EBOOK

How to Find Success With 3D Printing in Manufacturing and Engineering

E-book With 14 Real-World Case Studies

formlabs

INTRO

In this e-book, hear from 14 different companies about the impact Formlabs 3D printers have had on their business. From a small company launching a Kickstarter project to the world's largest furniture manufacturer creating and updating production tools, in-house desktop 3D printers are cutting costs and boosting productivity. Each use case is different, but the outcome is the same: companies using desktop 3D printing to greatly improve their business efficiently and deliver better products. Some users have only recently invested in 3D printing, while others have been long-time printers honing their craft and driving results across business units. Whether you're just starting to think about in-house 3D printing, or have been printing for years, there's always something to learn from other users' success.

Each section of the e-book focuses on different benefits Formlabs' users derive from 3D printing. You'll learn how 3D printing is enabling rapid prototyping, cutting costs, fabricating production tools, creating functional parts, and introducing hybrid production methods into engineering workflows.

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RAPID PROTOTYPING

Rapid prototyping is used in a variety of industries, by Fortune 500 companies and small businesses alike, to speed up development, decrease costs, improve communication, and ultimately create better products. Prototyping is an integral part of any design process; holding a physical draft of a product illuminates the ideas and concepts behind a feature, allowing for functional parts to be produced and tested at a fraction of the cost of traditional methods.

The emergence of desktop 3D printing has enabled rapid same-day prototyping to become feasible in product development, allowing companies to get better products to market faster than their competition. With in-house 3D printing, engineers can quickly iterate between digital designs and physical prototypes. It is now possible to create multiple prototypes within the same workday and carry out quick iterations of design, size, shape, or assembly based on the results of real-life testing and analysis.

Formlabs desktop printers have become integral in many businesses' rapid prototyping processes. In this section, you'll meet four teams driving innovation and improvement over traditional processes with the addition of 3D printing.

Find out how:

PLAATO developed the world's first fermentation analyzer airlock for homemade beer, printing prototypes non-stop for multiple days, creating cleat parts, and using the prototypes to communicate with manufacturing partners.

A&M Tool a machining and metalworking design services firm, is using desktop 3D printing to move part creation in-house, increasing capacity and reducing costs while allowing employees to "think completely outside the box."

Paralenz created 20-25 different camera housings for an underwater camera, prototyping early and often to optimize their design. These designs were then brought to meetings with manufacturers in China to better facilitate production orders.

Wohler a Germany-based manufacturer of metrology and inspection technology, worked with multiple materials to create prototypes depending on the parts' functional needs and conduct a range of tests based on user requirements.

PLENGoer Robotics quickly generated prototypes to reduce the time engineers spent thinking about exact parameters and configurations, increasing ideation and testing with physically printed parts.

PLAATO

INDUSTRY: Homebrewing
APPLICATIONS: Creating of optically clear custom parts.

PLAATO cut costs by bringing prototyping in-house, enabling the creation of over 1,000 variants of an optically clear part.

Michael Kononsky, a product designer by trade, and Pål Ingebrigtsen, an engineer, met at a startup event in Norway in 2015. Working in their first job after graduation, both were thirsty for brewing something new.

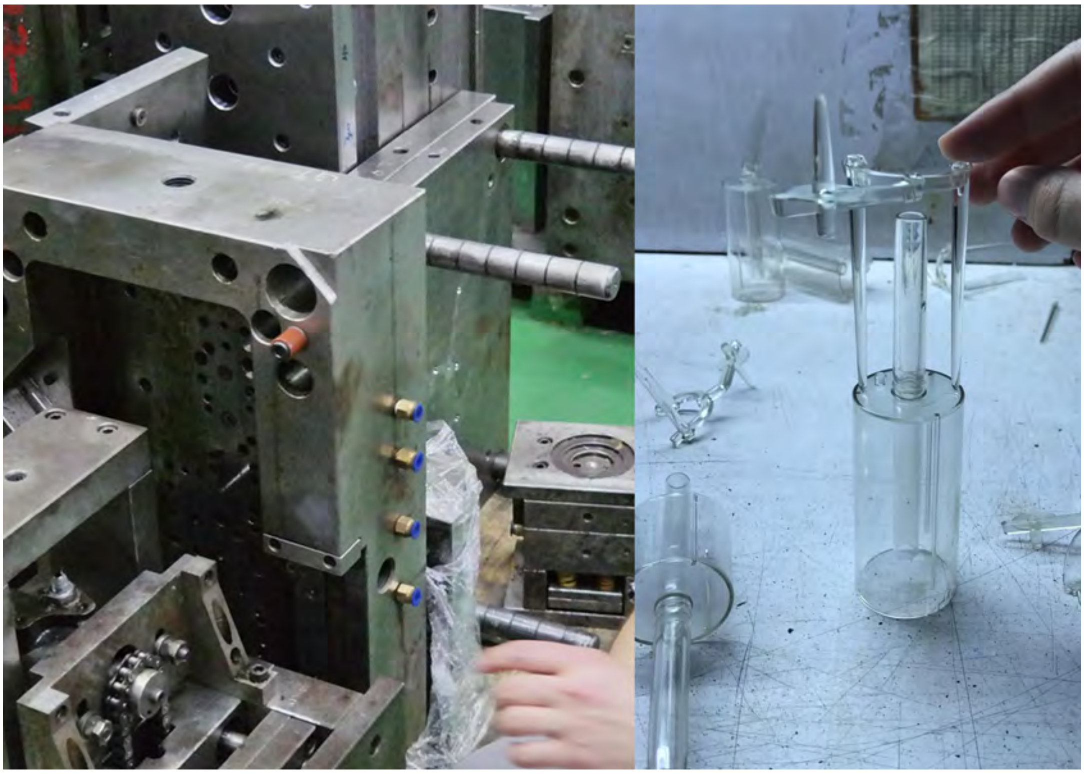
Eager hobbyist beer brewers themselves, the duo saw a business opportunity in the worldwide emergence of craft breweries and the increasing popularity of homebrewing.

More than 1,000 prototypes later, PLAATO, the first brewing product that measures CO2 released during fermentation to empower brewers with data, was born.

“We thought that it’d be great to gather data from beer brewing, because the fermentation process, where the magic really happens, is a complete mystery box. You close the bucket for two weeks and then you don’t know what’s going on inside. You don’t know if it’s good, if it’s bad, if it’s too warm or too cold,” Kononsky said.

“Then you open it and say, ‘oh damn, this is infected,’ or ‘oh yeah, that was great.’ But then, you never manage to recreate it and you can’t share the recipe with a friend because you don’t really have the proper tools to do that.”

Kononsky and Ingebrigtsen looked at many different methods and even found perfect flow meters that can measure the CO2, but the brewing environment brought up unique challenges.



The final parts are injection molded from Tritan (copolyester) material.

"[For brewing], a product should withstand spillage, corrosion, and accidental dropping. You have to have everything cleaned and sanitized, as you're always risking contamination and infection. We had to develop a method that monitors fermentation activity without putting any sensors inside the brew because it's so sensitive to invasive measurements. Basically, we needed to create a product that measures the activity without touching the beer," Kononsky said.

To answer these unique parameters, the entrepreneurs decided to develop an optically clear airlock.

There are only a few ways to prototype optically clear parts; Kononsky tried CNC machining and outsourcing to service providers, but found both methods slow and expensive. "We calculated that for the price of 3-4 iterations, we can buy a new Formlabs 3D printer," said Kononsky. Having a 3D printer at their desk allowed the team to test multiple iterations a day, at low cost.

> *"We printed all day every day until we managed to get something right because the threshold of trying something new was so low. The unit cost for these clear parts is almost insignificant. It added a lot of value, it's like having another designer in the team." said Kononsky.*

"I think we had around 1,000 different clear part prototypes—we produced six prototypes a day, then iterated the design in Solidworks based on the conclusions, while having a new part already printing. We measured the bubbles, measured the flow, tweaked the parameters, and used some machine learning and empirical learning. Working so closely with the parts, you actually understand the material and its properties."

Kononsky and Ingebrigtsen required highly accurate prototypes that can be taken apart, cleaned, washed, and reassembled to click exactly at the same spot so that the sensitive sensor would give the correct reading in their next test.

"It's the same working principle like a pen, with a cup that you click on and that stays at the exact same spot. We managed to solve it with a combination of the Clear Resin for the clear part, and the Tough Resin for the bottom. Clear parts are very rigid, while the Tough bottom parts had some flexibility to allow for a tiny groove, some ribs, and a double-click ring. We managed to simulate the final product's behavior; it worked 100% correctly just like the plastic [injection] molded part," said Kononsky.

"Basically it was our pre-golden sample. With injection molding, you have to account for some shrinkage that you don't have with 3D printing. Also, the surface tension and the plastic properties were a bit different. But we had a benchmark in our hands, so we could work together with the engineers and iterated the mold a couple of times to reach the same tolerances that we got from the 3D printer. We just had to replicate the properties based on the printed prototype, not the other way around. So it was not a black hole that we were guessing and trying, we really had the benchmark that worked as an anchor," said Kononsky.

The entrepreneurs recently received the prestigious Red Dot Award as a recognition for the "aesthetically sophisticated design of PLAATO that brings the airlock traditionally used in beer brewing into the digital age."

"I'm telling my team all the time, I have no idea what I would have done without the Form 2 printer. I seriously think we wouldn't have managed to understand even our production abilities. We would have a big bulky part with some window made of glass, nothing close to these proportions and size," said Kononsky.

PLENGoer Robotics

INDUSTRY: Robotics
APPLICATIONS: Prototyping robot castings.

In-house prototyping resulted in a cost reduction of 95 percent compared to outsourcing a CNC-milled master. Production time was reduced by about 86 percent, taking only two days instead of two weeks.

Natsuo Akazawa wants the world to rethink robots: what they look like, where they live, what they do, and even how they're made.

Akazawa is well on his way to achieving his dream of developing a new kind of robot, produced in what he calls a "futuristic factory." He's the president and representative director of PLENGoer Robotics, which shipped its first product, a service robot called PLEN Cube.

PLEN Cube isn't meant to live in a factory, but in your home or hand. It's an expressive but powerful hybrid of personal assistant and portable companion.

Akazawa's futuristic factory is fueled by 3D printing. Team members across countries coordinate designs in real time over cloud-based CAD and prototype in-house using desktop stereolithography (SLA) 3D printing, saving upwards of 85 percent in time and costs for some components. Ultimately, this digital design process inspired the company to rewrite and revamp its product development strategy.

PLEN Cube's appearance is essential to its success, so the ability to rapidly prototype and test its enclosure and the mechanics that enable it to move proved crucial to the development process. 3D printed enclosures were also used in the prototypes for videos and crowdfunding.

The PLENGoer Robotics team understood the value of in-house 3D printing for fast, cost-effective, prototyping and initially started with a fused deposition modeling (FDM) system, but found that it couldn't fully replace outsourcing.

"The biggest problem was the lack of measurement precision. In the end, the prototype output with the FDM 3D printer could be shown only as a rough prediction of the final product, and in the final stages of the prototyping process, parts were produced through outsourcing using an SLA 3D printer in order to ensure correct measurement precision and finishing," Akazawa said.

"However, outsourcing increases cost, and even working with quick contractors would take one to two extra days. A decision was made to purchase an SLA 3D printer, and after asking feedback from some of our engineer friends, we purchased Formlabs' Form 2."

Right off the bat, PLENGoer Robotics saw significant cost savings from 3D printing in-house with the Form 2.

Directly printing a prototype of PLEN Cube's outer casing resulted in a cost reduction of 95 percent compared to outsourcing a CNC-milled master. Plus, production time was reduced by about 86 percent, taking only two days instead of two weeks.

"In the case of outsourcing, we can't make multiple prototypes on each occasion. The great advantage of the Form 2 used in-house is that we can repeatedly carry out tests," said Kazuya Shibata, an engineer at PLENGoer Robotics.

The PLENGoer Robotics team used PreForm software to optimize their prototypes before sending them to the Form 2 SLA 3D printer.

"Another great advantage for engineers is the ability to reduce time spent thinking about various parameters and configurations. As soon as a thought pops into my head, it can be verified immediately by printing with the Form 2."

In-house 3D printing also helps Shibata coordinate with colleagues in China and Ireland. Engineers across offices merge design data using cloud-based Autodesk Fusion 360 software, then, in Japan, Shibata prints designs over Wi-Fi on the Form 2 to evaluate and share with the team. Soon, they hope to integrate Form 2s in every office.

"Even we are surprised that we can experience such prototyping and development processes," Shibata said. "The impact on us has been great."

"While truly experiencing a new development process, we have been able to establish certain cycles," Akazawa said. "Using the expertise gained from PLEN Cube, we want to increase projects that are on a slightly smaller scale. We also want to refine PLEN Cube with second and third iterations. Through such a development process, we believe that tools such as 3D CAD and the Form 2 will be absolutely essential."

A&M Tool

INDUSTRY: Machining and Metalworking
APPLICATIONS: Prototyping for different types of tooling.

Producing in-house jigs and fixtures, accelerating prototyping, and shortening feedback loop with a single Formlabs printer.

Speed has always been linked with success for production environments. In an ever-changing technology landscape, manufacturers and machine shops have the opportunity to add new tools to increase efficiency, but face the challenge of choosing technology that can reliably and cost-effectively scale modernization.

In addition to large-scale manufacturing automation equipment like the PALLETECH, last year the shop added an industrial-grade desktop SLA 3D printer to expedite projects and open capacity to supplement an understaffed engineering team. They've since scaled 3D printing applications from prototyping and communications models to quick-turn production tools and end-use parts for custom machinery.

"3D printing has become a priceless tool in our toolbox," said Guido Jacques, vice president of operations at A&M. "It's kind of a cliché, but it's really allowing all of us to think completely outside the box."

In order to effectively replace prototyping that would otherwise be done through more labor-intensive processes or workflows, 3D printing had to be both cost-effective and precise. Ryan Little, an A&M Tool mechanical engineer, researched which 3D printer would best match for their needs, and selected the Form 2.

“Part of our pursuit in looking for a 3D printer was being able to have something that could run pretty autonomously with limited training,”

Little said. “We can run some of the CNC machines downstairs, but they’re rarely available, and programming a CNC machine for an advanced job in Mastercam, or just trying to do it on the controller itself, can take hours. Starting up a job with Formlabs PreForm software takes 10 minutes, and it’s really simple.”

For prototyping, the shop started using 3D prints to test fit and function. 3D printing allows Little and the team to make parts much faster and utilize all hours of the day, setting up prints to run overnight then using parts the next day. Printing is especially helpful for geometries that are costly and time-consuming to produce on a CNC machine.

“The printer almost feels like an auxiliary tool in addition to CAD,” Little said. “We do a ton of prototyping for different types of tooling. If we didn’t have the Form 2, many prototypes would just stay in CAD until we were ready to machine, and there would be some things that would never get made or designed because it wouldn’t be practical.”

Many of the parts A&M produces have fatigue and/or load-bearing applications. Little often uses Formlabs Tough Resin for prototyping strong, functional parts and assemblies that will undergo brief periods of stress or strain.

The A&M engineering team also uses 3D prints to help communicate with machinists and welders, turning complex drawings into physical models. Increasingly, the machinists themselves are making requests for models.

“Sometimes we’ll see a finished part and realize a hole was tapped in the wrong direction, or a feature wasn’t supposed to be on a certain side–and that’s not something you can fix. When that happens, the part is pretty much finished, and you have to restart,” Little said.

Changing out the tooling and setting up CNC machines can take hours, whereas preparing a job for 3D printing takes less than 10 minutes.

The A&M Tool engineering team uses the Form 2 3D printer regularly to produce parts for prototyping, tooling, and more. Engineers found that the number of use cases rapidly expanded once 3D printing was integrated into their workstation.

“We have talented machinists here who can interpret drawings with so many call-outs on them that you almost can’t see what’s happening, but even still machinists will have to ask for clarity, especially when there are more complex geometries like undercuts. Now, if we have an assembly or SolidWorks file, we’ll make a scale model of the part and give it to them, and they love that. The whole shop is actually starting to draw on it.”

“3D printing allows us to do a lot of things that the shop can’t easily do–geometries for making parts that would be a nightmare on a machine, etc.” Little said. “It’s given a shop a real advantage.”

“It will justify itself with helping you do things that your customers aren’t thinking about at the time of purchase. We’ve been very happy with the Form 2, and very happy with the decision that we’ve made,” Jacques said.

Paralenz

INDUSTRY: Electronics
APPLICATIONS: Functional prototyping and example parts for overseas manufacturers.

The ability to prototype seven or eight different designs completely changed the way the company designed its camera. Paralenz was able to create astonishing prototypes that look, feel, and work like the final product.

Michael Trøst and his team have been involved in product development and consultancy for more than 15 years. When their colleague Martin, an avid diver, saw a gap in the market between the all-round action cameras and the high-end diving cameras, they decided it was an opportunity.

Months of research, development, and several iterations followed. Using a Form 2 3D printer, they created astonishing prototypes that look, feel, and work like the final product–and what's more, survived depths of 150 m and saltwater testing.

Using these prototypes to create their marketing materials, they turned to crowdfunding to recruit a devoted group of beta testers, and raised $468,470 from 1,153 backers. But one challenge remained: arranging for the manufacture of the camera in Asia.

Martin wanted to develop a diving camera, claiming that there was a gap in the market. GoPro and other all-round action cameras are not really made for diving, and price-wise there's a leap to high-end cameras where you have an aluminum housing, flashlights - altogether a much larger and more expensive setup. He was looking for an easier, cheaper way to capture his own dives.

After investigating his options, Martin settled on the Form 2 desktop 3D printer. Martin felt the machine would be able to serve multiple purposes, printing looks-like prototypes that also retained the properties needed to test their camera in salt water.

3D printing was used by Paralenz throughout the design process. They prototyped early and often. First, they started by talking to divers, who showed the team which features were most important. This type of customer research narrowed down the list of must-haves on the product.

The team started with 3-4 different basic designs, before settling on one. They tested four different sizes and printed models to evaluate the volume and weight, how they handled.

Potential customers were asked to select the one they liked best. The team created different versions of a button and tested them wearing gloves, before settling on the one that worked best. Altogether, Paralenz went through seven or eight different designs, all of which were printed.

Next, the team drew up the parts. With such a compact product your design freedom is limited, so they spent a lot of time figuring out how to optimize the design, while making sure that it accommodates all the required features.

Martin noticed that as he developed the internals, key components started to change.

“The battery is a bit smaller than the original, because of new sensors, lens, and some other parts. All of the changes made in the camera were made of 3D prints of - altogether iterating about 20-25 housings on the Form 2 in a matter of a few months.”

Once the parts come out of the printer they are cleaned, sanded and painted - it’s all a matter of practice. The lens is cast, with a 3D printed master created first, then made a silicone mold to cast the part. The logos are printed on an inkjet printer that can fit taller parts. The Form 2 saves man-hours, because it’s closer to being finished straight out of the machine.

“FDM models take about 3 times as long to get a high-end finish, and with a lot of parts you cannot even get the same finish on those models, regardless of the amount of effort expended,” Trøst said.

Besides allowing for rapid iterations in the development process, working with the Form 2 has saved Paralenz quite a lot of money. They used to have a large budget for SLA models - for this project alone, the team spent $15,000 on SLA parts. Buying a Form 2 and all the materials was less than a third of that, so it has already paid back the initial investment multiple times.

The team felt that the Form 2 was a fantastic machine, and it saved them a lot of time. Before they would have to do many tasks by hand or by CNC milling, which both required additional skills. The Form 2 simplified and sped up processes, eliminating the need to learn and use a CNC milling machine along with other tools.

The team went to initial meetings with different manufacturers in China, and brought prints of the parts they were supposed to produce so they could say, “This is the product. This is what you’re supposed to do.” Instead of just 3D models, the Chinese manufacturers received the actual physical part.

Sometimes really unexpected errors arise in China due to communication, especially when we’re talking about in-depth technical details. And these errors are costly. Even the smallest thing can set back development by a week - critical ones most likely by weeks. The team worked with 17 different Chinese suppliers who all create custom parts, so it was vital that everyone was on the same page. Having the actual parts from the 3D printer made it much easier for the supplies to understand the product.

Paralenz's high fidelity prototypes and parts, ready for showcasing.

On one occasion, the team at the Chinese manufacturing center thought the 3D printed part was the final piece, and they didn't understand why Paralenz needed anything made. They were saying, "You want us to make this, but you already have it. Why do you need..." and the team had to explain that "it's not real. It's a prototype."

Paralenz is now thinking of buying another Form 2 and setting it up in China so they can save time on the next products in development. They have a colleague living in China that can receive files, and have the parts printed within a few hours before taking them directly to the manufacturers. Currently, shipping parts to China takes 2-5 days depending on freight costs, so having someone on the ground will speed up the process even more.

Wöhler

INDUSTRY: Industrial Equipments
APPLICATIONS: Prototyping for casting and final manufacturing.

Wöhler used multiple types of resins to create functional prototypes, reducing the lead time for the production of a prototype from several days to a few hours.

Aside from the benefits of iterative design, prototyping helps engineers finalize products before committing to manufacturing, avoiding costly mistakes.

Sebastian Leifels, product designer at Wöhler, a Germany-based manufacturer of metrology and inspection technology, needed to design a prototype with close-to-final aesthetics and function to get a new product ready for casting and final manufacturing.

He was posed with a challenge: to create a look-like, works-like prototype to get a new product ready for casting and final manufacturing. As a product designer at Wohler, Sebastian needed to design a prototype that had the final product's aesthetics and function. He explains, "It is extremely important to prevent mistakes at this stage of the design process. Changes to the casting device as well as the end product are expensive. The costs range from a three-digit up to a five-digit euro figure."

This risk was on Sebastian's mind as he prototyped the Wohler HF 550 Wood Moisture Meter, a device that measures the level of moisture in firewood and wood products like pellets and wood chips. Here are a few lessons that Sebastian and the Wohler team learned during their rapid prototyping process.

Sebastian had to make changes to prototypes quickly and easily to stay on deadline, so he decided to use desktop 3D printing. He opted for a Formlabs 3D printer, which uses SLA technology to create precise models in hours. He recalls, “The production of a prototype dropped from several days to a few hours. As we used the printer to design parts for the device housing, we saved several weeks in the entire development process.”

Keeping production in house enabled the Wohler team to have greater control and speed in the design process. Sebastian recalls, “If it was needed during the current development state, we ran the printer day and night for several weeks.” With a large number of prototypes, the team could test out more ideas along the way, resulting in a better final product.

Early in the design process, Sebastian had a desktop 3D printer that used Fused Deposition Modeling (FDM) technology that cost more than four times the Formlabs machine.

> *Yet the FDM printer could not produce accurate details. “The printer allowed greater precision,” Sebastian explains. “Our previous machine had a minimum layer size of 0.178 mm. The Formlabs 3D printer had a minimum layer size of 0.025 mm.”*

He continues, “Even if you choose the same layer size, the Formlabs printer will always have smoother results.”

To prototype the wood moisture meter, Sebastian had to incorporate several different materials. The team’s initial FDM 3D printer could not print flexible materials, so they originally went through a complex process. First, they designed a trial casting model and printed it on the FDM printer. Then they painstakingly post-processed the casting model to smooth the surfaces. Finally, they grouted the model with rubber compound. Sebastian recalls, “This was a time-consuming process, and we still couldn’t reach the fine details. Now, we simplified our process by directly printing detailed parts.”

Sebastian used Black Resin for the case and Flexible Resin for the keypad. The keys had to compress when the user pushed them, so the button walls had to be very thin yet durable. He says that Flexible Resin allowed the team to “conduct a wide range of tests with the prototypes without any damages or functional constraints of the part.”

Sebastian and his team now use their Formlabs 3D printer for all prototypes at Wohler: “With in-house 3D printing, we have the advantage of testing the parts for each device before mass production. The risk of reworking the device later is low.” Using a single machine that produces multiple materials opens up new prototyping possibilities for the Wohler team. Although in-house 3D printing saves them time and money, the biggest advantage is the ability to create better final products.

PRODUCTION TOOLS

3D printers have become true manufacturing tools over the last decade, driven by improvements in printer technologies and materials. 3D printing excels at creating the complex geometries needed to replace and upgrade production tooling, enabling longer machine up times and higher productivity on manufacturing lines.

Section one discussed why rapid prototyping is a natural first step for many firms looking to explore the implementation of 3D printing. After testing the waters with prototyping, engineering teams often find other intuitive ways to use 3D printing to improve production and supply chains, cut lead times, and reduce costs associated with outsourced tooling. Just a single 3D printer can change the way teams create and view production tools, from jig and fixtures to custom tools to augment current machine setups.

The ability to create in-house jig and fixtures with no minimum order quantities simply wasn't possible 10 years ago. Engineers can encourage a culture of continuous improvement, rapidly responding to issues on the manufacturing line which used to cause headaches and downtime. From a local foundry to a Fortune 500 company, 3D printed parts are reducing time- and resource-intensive steps in production processes and opening new business opportunities with the flexibility of cost-effective customization.

In this section, you are going to meet firms reducing costs and increasing innovation by incorporating 3D printers into their production workflows to create production tooling.

Find out how:

The University of Sheffield Advanced Manufacturing Research Centre (AMRC) introduced 3D printing to speed up hundreds of projects for their industrial partners, quickly scaling to create a large printer station available to hundreds of engineers.

Ashley Furniture the largest furniture manufacturer in the world, runs two Formlabs 3D printers a minimum of 40 hours a week to eliminate outsourcing, driving cost savings across the company.

Pankl Racing used in-house 3D printing for prototyping, masking, and manufacturing

Systems various jigs and tooling. They reduced lead times for jigs and other low-volume parts from two to three weeks to less than a day.

AMRC

INDUSTRY:
Manufacturing Research
APPLICATIONS: Multiple applications, such as creating protective caps for drilling, a robot gripper bracket, washers, custom rollers, and more across multiple projects and teams.

An on-site additive manufacturing station with a fleet of 12 Formlabs 3D printers provide open access for hundreds of engineers working on diverse projects.

The University of Sheffield Advanced Manufacturing Research Centre conducts world-leading research in advanced machining, manufacturing, and materials, helping over 100 industrial partners ranging from global giants like Boeing, Rolls-Royce, BAE Systems, and Airbus to small companies who want to become more competitive. These business partners approach the AMRC with specific challenges, and AMRC researchers use the newest technologies and processes to develop concepts and solutions to the point where the partners can implement them in their factories.

Recently, the AMRC's Design and Prototyping Group installed a new additive manufacturing station with a fleet of 12 Form 2 SLA 3D printers that provides open access to 3D printing to hundreds of engineers working on diverse projects across the site.

"It has vastly streamlined our operations. [At any point in time], we have hundreds of projects live with hundreds of engineers. Now that staff has access to 3D printing, for every project that requires additive manufacturing, the time to produce components has been streamlined from probably around a week and a half to hours," said Mark Cocking, the polymer additive technical lead at the Design and Prototyping Group at the AMRC.

The AMRC Design and Prototyping Group works with researchers across the AMRC site to develop everything from conceptual designs to fully functional prototypes for a range of industries.

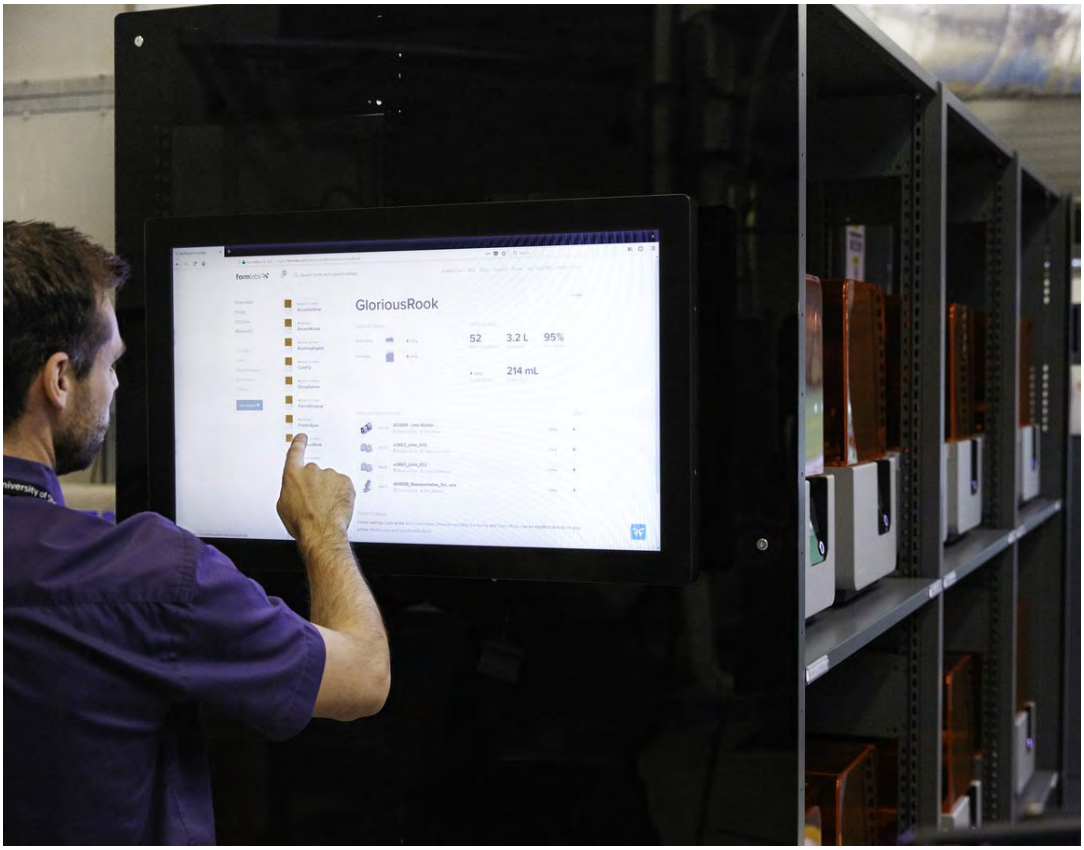
“Some of the parts that we create are just concept demonstrators but very often we also create jigs, fixtures, and other bespoke components that are fitted to machinery for different research programs,” Cocking said.

Previously, the center used a single industrial SLA 3D printer that only a couple of people were trained to use due to the complexity of the process. All jobs at the AMRC that required additive manufacturing would pass through these individuals, which slowed down the workflow and hindered innovation.

“It was far better for our site to open that knowledge up, to train many users and allow them to use the system and then increase their knowledge based on use. We found that if they have the opportunity to use the units, they’re able to come up with more and more concepts for additive manufacturing components,” Cocking said.

“Engineers no longer have to go through the procedure of paperwork to be able to turn an idea into a printed part; they can just come down here and do that straight away. It breaks down barriers in terms of internal concept development and there’s more innovation that can take place. They can produce components within hours that can be on the meeting table for a partner the same day or maybe the next afternoon.”

The Design and Prototyping Group currently has 12 Form 2 3D printers set up in a station. Cocking arranged the printers on one side to provide easy access to all of the different resins and the prints, and set up a wet area on the other side with four Form Wash and four Form Cure units for cleaning and post-curing. There’s a section on the side that has storage for build platforms, PPE, instructions, risk assessments, and also a buffer zone for prints that are passing through the system.



The technician interfaces with the 12 machines via a touchscreen on the side wall of the station that runs Formlabs’ Dashboard software and provides information on the status of prints and the material levels.

The back side of the station contains a wet area with four Form Wash and four Form Cure units for cleaning and post-curing as well as some space storage.

A single technician manages the area and looks after all of the printers. The technician interfaces with the 12 machines via a touchscreen on the side wall of the station that runs Formlabs' Dashboard software and provides information on the status of prints and the material levels. When the staff comes to the center to use the machines, all they have to do is press the print button.

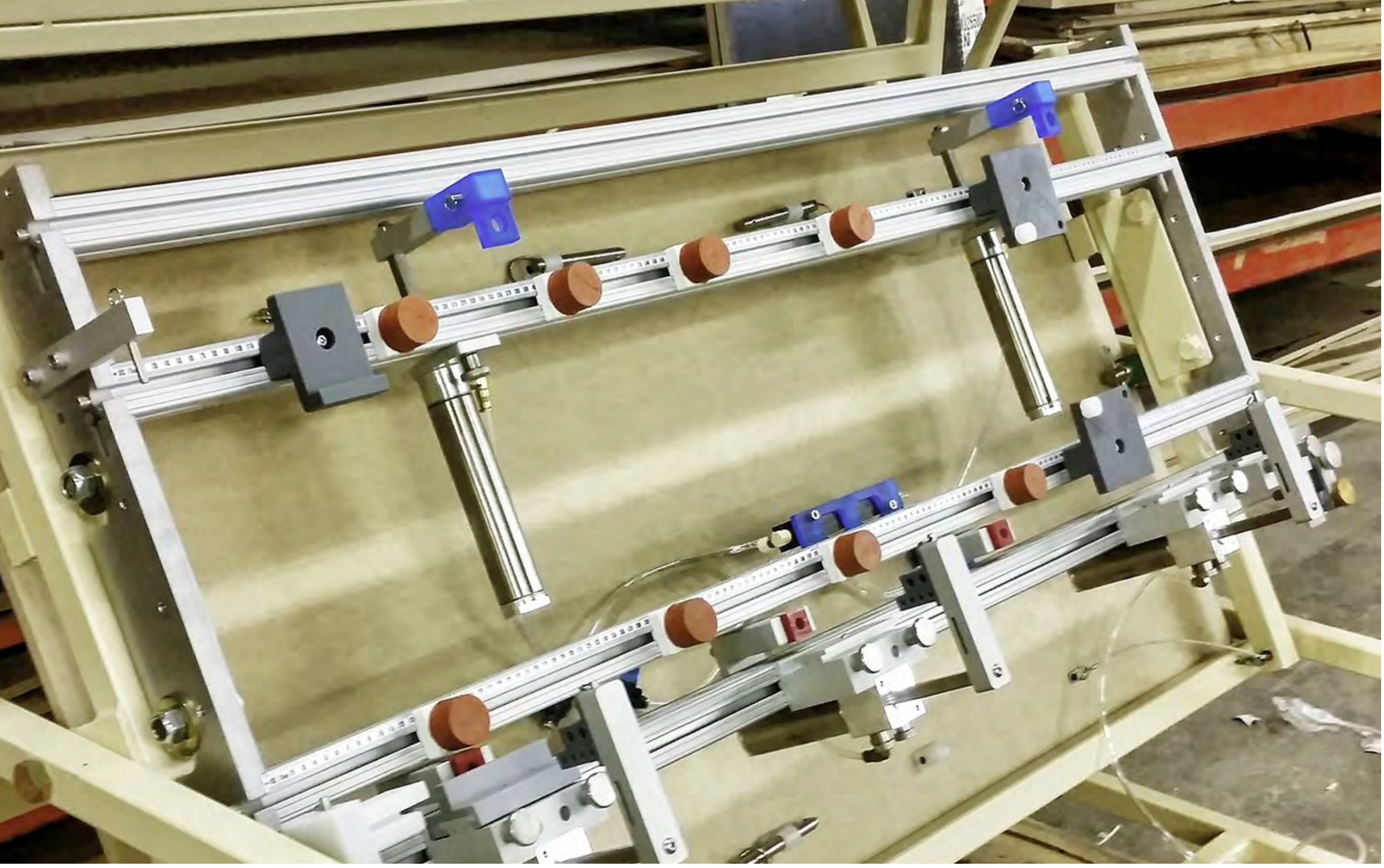
"I needed units that staff members can be easily trained on and be successful with so that they want to use them again. The Form 2 is the first small SLA machine that I've used where I thought, 'yeah, this is a game changer.' In terms of machinery, it's so simple to use," Cocking said. "The software is very intuitive, engineers can pick it up very quickly. It's easy for them to understand and grasp the basics, and from there on, they can learn themselves and can push their additive experience themselves. Currently, we have just over 100 engineers trained to use the Form 2 bank."

> *"You can bring the release date of your product forward by months just by having access to additive manufacturing"*

The AMRC's industrial partners seem to agree, as the success of the open-access platform has also grabbed their attention.

"They could reduce turnaround time on custom components from weeks down to hours. Having ordered custom components myself, I understand the lead times and I understand the impact it can have on innovation, but also, ultimately, on the release date of a product. You can bring the release date of your product forward by months just by having access to additive manufacturing."

AMRC has leveraged recent advances in additive manufacturing to significantly impact production cycles. By reducing lead times and moving product releases forward by months, the team is able to drive additional revenue and free up time to work on new projects.



Ashley Furniture

INDUSTRY: Furniture
APPLICATIONS: Machine Replacement Parts, Plus In-House Jigs and Fixtures.

For certain applications, part per-cost declined by 31% as 3D printing was brought in house. Formlabs 3D printers have opened up more opportunities for Ashley Furniture employees to creatively solve problems, increasing productivity and reducing costs associated with outsourcing.

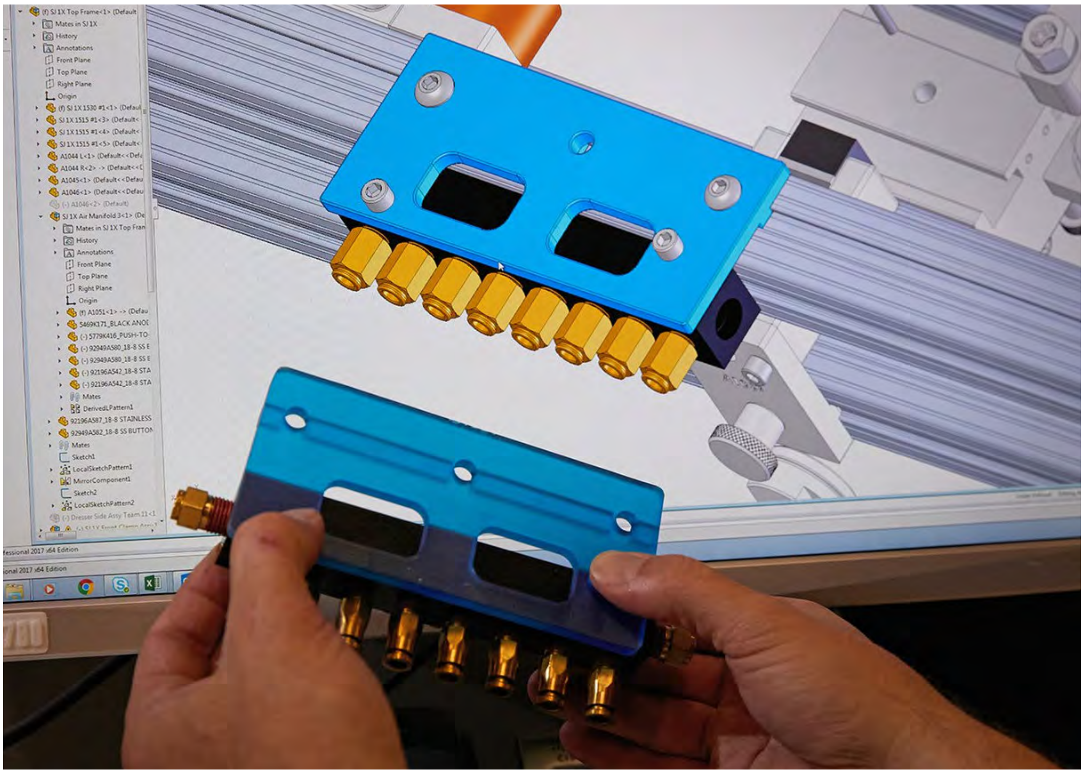
Shortly after Ashley Furniture brought in the company's first stereolithography (SLA) 3D printer, one of their production engineers had an idea. Was it possible to replace machined alignment pins with end-use 3D printed parts, avoiding the long lead times and minimum order quantities of outsourcing?

The answer was yes, and led to more questions.

With a culture that encourages employees to actively participate in continuous improvement processes, Ashley Furniture applies advanced technologies to supplement labor and maximize the value of their staff, sourcing process improvements and innovations from the people closest to the work.

"Automation has really allowed us to remove some of that heavy physicality that manufacturing has had the stigma of over the last 50 to 60 years. We don't have employees doing that heavy bulk work all day long anymore. Let the machine do that. Let the employee use their mind, try to better the process," Pieters said.

"We put our first robot in five years ago, and now you can see as you tour our facility where else we've added automation. 3D printing has taken that same kind of growth pattern."



The universal setup includes an air manifold mount printed in Tough Resin.

Over the past 30 years, Ashley Furniture production engineer Brian Konkel has worked in the company's design, engineering, and manufacturing departments, finding opportunities to apply 3D printing within each discipline.

Prior to applying 3D printing on the factory floor, Ashley Furniture had already been using in-house 3D printing for prototyping. In fact, the company had previously used 3D printing for decades, outsourcing parts here and there since the '90s, and eventually bringing in a low-cost fused deposition modeling (FDM) printer when order volume started to increase.

The company started printing more and more in-house, but quality became an issue. The team upgraded to laser-based SLA, purchasing the Formlabs Form 2 3D printer.

"We realized that we were looking for a little better surface quality and closer tolerances. SLA 3D printing on the Form 2 allowed us to create things like snap-fit features for different fastening components," Konkel said.

"One of the nice options with the Form 2 is the variety of materials that are available. We could start printing a component, and if that particular material was not exactly what we're looking for there are other options available."

Things took off once the team brought the Form 2 3D printer in-house. In addition to prototyping designs, Konkel found areas to apply 3D printing in production. Printing volume increased so much that six months later the company ordered a second printer.

"We currently run both Formlabs printers at a minimum of 40 hours a week," Konkel said.

Printing parts was a quick, low-risk solution for testing and implementing ideas for boosting efficiency, from saving time and money by creating replacement parts in-house, to discovering creative solutions that fundamentally changed how the company organizes the factory floor.

3D printing the alignment pins alone saved significant time and costs from outsourcing the parts in nylon.

Instead of purchasing a completely new assembly pod for $700, the company 3D printed the part that needed a replacement for just $1.

“We had been previously sourcing [the pins] from a machine shop with a large minimum order quantity of 1,200, turned on a lathe out of nylon. Now, we’re able to circumvent that, and literally cut the price in half,” Konkel said.

Not only has printing the part in-house saved resources outsourcing, but also in downtime changing out between jobs. Previously, a special fixture was created for each board. Now workers use a setup sheet to quickly relocate pins on a simple grid work.

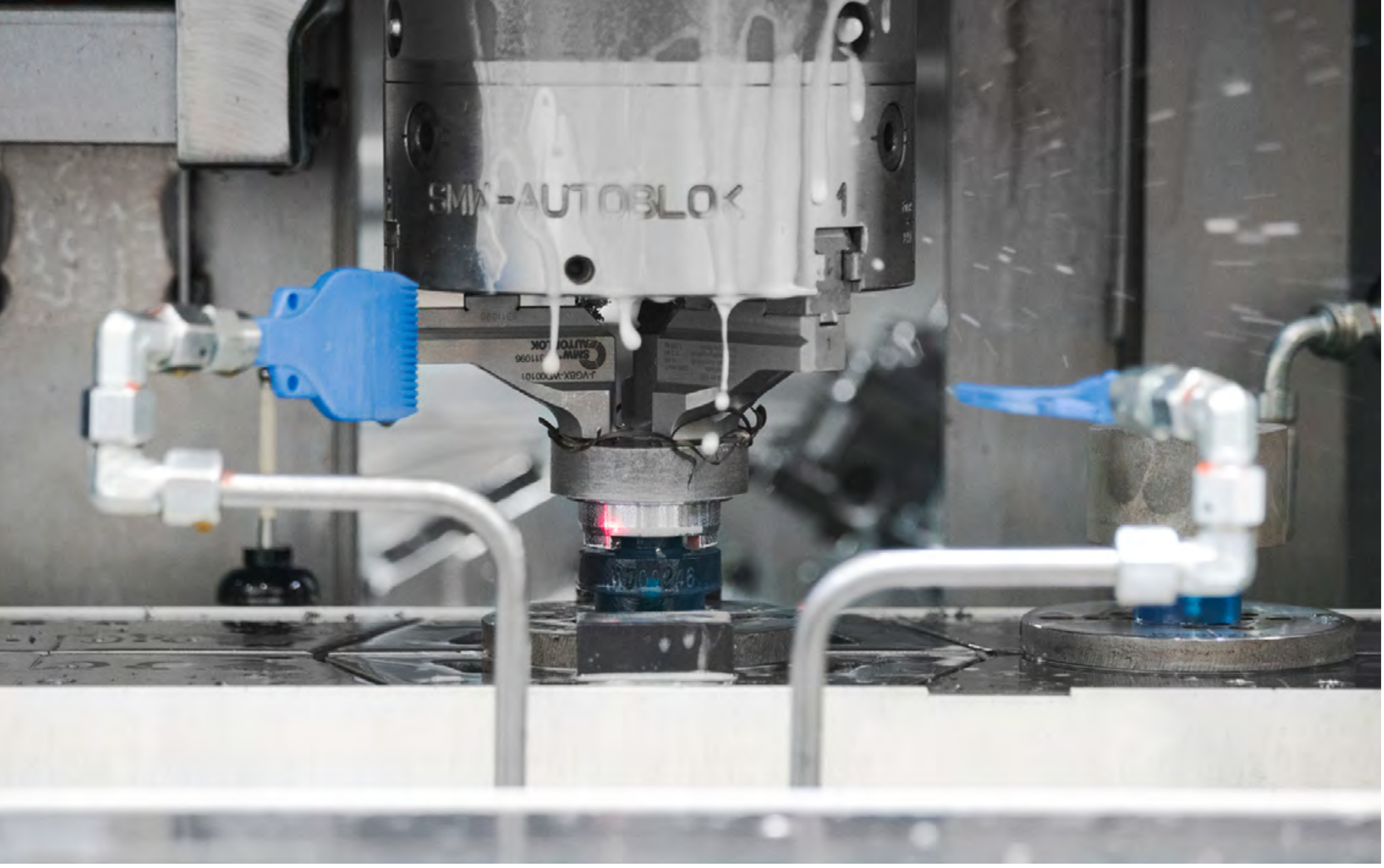
“With 3D printing, it’s obviously easy to replace [parts], but we were surprised of the longevity; some of these parts were getting three times what we originally expected, nearly nine months before they required a replacement,” Konkel said.

“For example, some parts are cycling once a minute, coming down and clamping to screw an assembly together.”

“Previously, we had been building each individual jig for a specific product line. With the 3D printing of the parts, it’s just simply replacing parts to adapt to different SKUs. We’ve literally replaced fixtures that are three feet by six feet with a simple bin system; it’s a two-minute setup time.” Konkel said

“It frees up jig builders from repetitive task to work on more pressing issues, from busy work to looking at more challenging items.”

“Tough Resin is a material that has worked quite well for us in the area of clamping fixtures, anything that we’re going to put on the end of an actuator. It has that impact resistance quality to it,” Konkel said.



Pankl Racing Systems

INDUSTRY: Automotive and aerospace components
APPLICATIONS: Affordable custom jigs and low-volume part production.

3D printing saved Pankl €150,000, a 80-90% cost reduction, while reducing lead times for jigs from two to three weeks to less than a day.

Pankl Racing Systems specializes in developing and manufacturing engine and drivetrain components for racing cars, high-performance vehicles, and aerospace applications with more than 1,500 employees, and worldwide subsidiaries in Austria, Germany, the United Kingdom, the United States, Slovakia, and Japan.

Every single part that Pankl makes requires a series of custom jigs, fixtures, and other tooling that are designed and fabricated specifically for that part. The result is a proliferation of custom tools, adding significant cost and complexity to the manufacturing process.

To fulfill tight production deadlines, process engineer Christian Joebstl and his team introduced SLA 3D printing to produce custom jigs and other low-volume parts directly for their manufacturing line in the company's new €36 million state-of-the-art manufacturing facility.

While 3D printing was initially met with skepticism, it turned out to be an ideal substitute to machining a variety of these tools, surprising even Pankl's demanding engineers. In one case, it reduced lead time for jigs by 90 percent—from two to three weeks to less than a day—and decreased costs by 80-90 percent, leading to €150,000 in savings.

Having been familiar with 3D printing from my education, I started looking and found the Form 2 3D printer after reading some reviews online. My colleagues understand the value in 3D printing now, but at the beginning, they were extremely skeptical. They thought 3D printing was more like a toy.

In our business, we expect that good equipment is inevitably also expensive. Most of our machinery starts at €100,000 and goes well beyond that. When my colleagues saw that the Form 2 only costs about €3,900, they asked me, “Why should we buy a toy?”

We ordered multiple custom sample parts to conduct tests, and it turned out that the 3D printed parts were capable. Holes and length tolerances were within the ±0.1 mm interval. I researched the material costs for my amortization calculation and discovered that a 3D printed set of the tooling for shot peening would only cost €45. I summarized this into a presentation for the board and took the parts to the kickoff meeting of the new gear plant. They were finally convinced, and we decided to buy our first Form 2, which we soon scaled up to three units.

Pankl was selected to manufacture entire gearbox assemblies for a well-known motorcycle manufacturer, but fell behind on their delivery timeline.

“Our schedule was tight because we had to produce many more gear types than expected. By the time we got to designing and ordering tooling, we were already supposed to start producing the first acceptance lots. We couldn’t just design the custom jigs and get them next day. If we had outsourced to traditional machining service providers, we would have had to wait six more weeks before we could start production—so we decided to produce the parts in-house on our Form 2 3D printers.”

Using a single Form 2, we can print a single jig in 5–9.5 hours, and running all three of our machines enables us to produce about 40 jigs within a week.

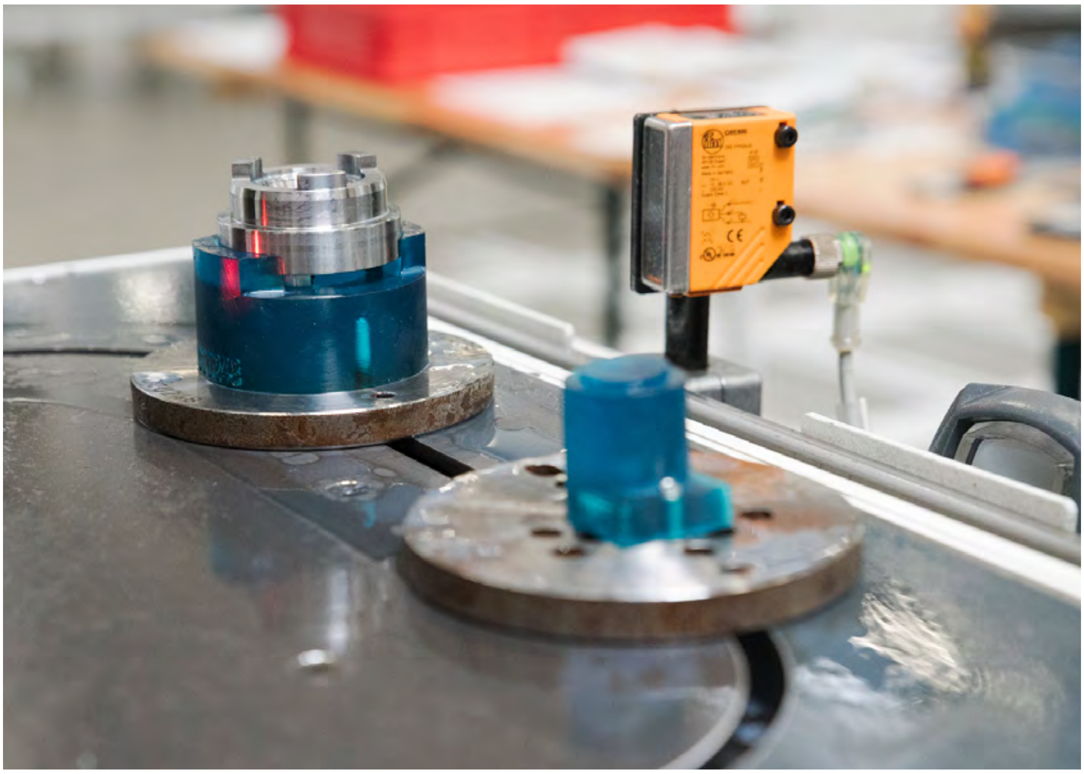
A simple machined jig costs about €40–50, but more complex parts can cost up to €300. 3D printing reduces these direct costs to €8.5–25, and significantly lowers overhead costs in design, purchasing, and storage, resulting in more than 90 percent overall cost reduction. Considering we’ll have to produce more than 1,000 jigs over the course of production, 3D printing will help the company save more than €150,000.

We’ve had lots of problems on the production line in the past because the cooling media in the lathe is very aggressive on plastic parts, and makes them brittle after some time. Parts 3D printed with Tough Resin have shown resistance against our cooling media, and they are strong enough to withstand the intermittent load that these parts have to endure. Holes and length tolerances normally lie within the ±0.1 mm interval, which satisfies the requirements for our jigs.

We’ve already produced more than 300 3D printed jigs to manufacture small batches of 200 parts of each gear for the trial production run. Soon, we’ll scale up production to 1,000-2,000 parts per batch and the production capacity of the facility will increase to more than 1.5 million gears per year.

Pankl has found numerous other use cases for 3D printing as well.

Prototyping, shot peening, masking, and manufacturing various jigs and tooling. For example, when we have a new connecting rod design, we 3D print prototypes to discuss complex features on the part. It’s much easier if you can look at the part, and hold it in your hands.



Each working stage in the automatic lathe requires a custom jig. The jigs are attached to the conveyor belt using standard shuttles.

Once we had to design a custom connecting rod for a customer, who wanted to verify if it'd fit into the building room of a cylinder and that it wouldn't hit the chamber or the cylinder head itself while turning. We 3D printed a prototype and sent it to them. Once they confirmed that the design worked, we could start production with confidence. The alternative would have been to produce a machined part, which would have been more expensive for the customer and required eight weeks of waiting time.

We also 3D printed special adapters for grippers on an automated handling system. To achieve the perfect grip between the gripper and the part, you have to take the negative of the part, and form the fingers of the gripper according to the shape of your part. Normally we would have milled or cast it, which would have been substantially more expensive.

Recently, we used Flexible Resin in a shot peening machine to increase the friction between the self-cleaning jigs and some other parts. The friction between the metal parts was too low to transfer the turning movement. I added some 3D printed elastic brakes in the tooling to increase the friction so that the turning movement was transmitted from the bottom to the top. Getting these parts from an external vendor would have taken weeks.

HYBRID MANUFACTURING

When most new users think of incorporating 3D printing into their business, they tend to consider direct printing; that is, using prototypes or functional-use parts right off the printer's build platform. However, hybrid production workflows which include SLA 3D printing enable numerous other processes to create high-quality end-use parts, including metal parts.

Hybrid production is where the 3D printed part is a few steps removed from the final creation, opening new avenues for creativity. This could be augmenting traditional casting methods, affordably creating detailed molding in-house, or enhancing traditional ceramic processes.

Hybrid workflows make up a big chunk of how companies are innovating with additive manufacturing today. The power of the SLA resin system is that advanced materials like Ceramic Resin, High Temp Resin, and Castable Wax Resin all work on a single desktop device costing ~$3,500. These different resin types enable various applications, such as investment casting, injection molding, electroplating, slip casting, and more.

In the section, you'll meet firms successfully using hybrid production methods to greatly expand what is possible with 3D printed plastics.

Find out how:

Google ATAP an internal experimental research team at Google, was able to reduce turnaround times and overcome complex problems by creating surrogate parts in High Temp Resin. 3D printed parts allowed Google to circumvent a complex supply chain issue during pre-production validation.

RightHand Robotics a robotics company working on the future of e-commerce order fulfillment, was able to use 3D printing to affordably build custom mold in-house for overmolding. They take an agile approach to manufacturing, avoiding expensive tooling and directly printing on a Formlabs machine.

Nervous System a design studio, enhanced the traditional ceramic firing and glazing workflow to create thin, unique geometries.

Google

INDUSTRY: Wearables
APPLICATIONS: Surrogate parts for overmolding

Google's ATAP created surrogate parts for overmolding to close the gap between prototyping and production, reducing turnaround time for a crucial component by 85% while saving over $100,000.

The Google Advanced Technology and Projects (ATAP) lab is uniquely set up to be a one-stop-shop for bringing hardware projects to life. The lab offers a vision into the future of both products and production, but uses problem-solving approaches that any company can learn from today, from an iterative mindset at every stage of development, to a technology toolset that enables agile, creative solutions.

In one case, the team's approach led to a process innovation that allowed them to circumvent a complex supply chain for the pre-production validation stage of an overmolded wearable device. Using Formlabs High Temp Resin, a 3D printing material with high thermal stability, they bridged the gap between prototyping and production, reducing turnaround time for a crucial component by 85% while saving over $100,000.

The team understood going into pre-production that the cost of first articles would be much higher than for a typical injection molded part. What they had not anticipated was the supply chain bottleneck; it took three weeks to source the overmolded electronic sub-assemblies they needed to run these tests. Beardsley needed to shorten that to ramp up production and ship product.

"You might shoot hundreds and hundreds, thousands of shots, to dial this in. The problem is when you're doing that with live electronics that have real boards that have been stuffed with real electronics and then sent off to the overmolder and then brought back, you've got this whole supply chain," Beardsley said.

Supports are placed on the High Temp parts so that markings were only on the parts that shut off, not the molding surfaces. This ensured that the parts did not require any additional sanding or finishing beyond a standard wash and post-cure cycle before use.

"The light went off when I was watching dollars and weeks just going in the garbage as we were trying to figure out how to dial in the tool. How do we prove this will work before we actually have to put live electronics in there?"

They needed to find a process and material that could stand in for the PCBA. The replacement had to be both dimensionally accurate and represent the exact geometry of the real sub-assembly so that fill could be characterized, and robust enough that the tool could shut off to the part without breaking or deflecting, leading to excessive flash.

"We knew we had to use a material that would withstand thousands of pounds of pressure, north of 250 °C," Beardsley said. "We were looking for high temperature resistance, high rigidity."

Beardsley reached out to Allen for help, and they came up with a plan.

> *The parameters were tight. Allen decided to try 3D printing the stand-ins, or surrogate parts, in High Temp Resin on a Formlabs SLA 3D printer. He knew he'd be pushing the boundaries of the material; the final parts would be injected at 270 °C at an injection pressure of 27,000 psi, on the higher end of the published heat deflection temperature (HDT) for High Temp Resin.*

"In order to get the small feature size and the shut-offs that we needed, we needed that resolution. It was really the combination of resolution and high temperature resistance that allowed us to use the Form 2 on this," Allen said. "We have the ability to select from many other fabrication technologies, but having the option to make these parts is really an important piece of our lab."

The team quickly got to work, printing some parts to test overnight.

"We had no time to redo any CAD on this. I opened it, exported an STL, and threw it at the PreForm software. Once we got that first batch of validation, we just cranked it. We ran 200 parts the first cycle and then we ran another 100 more," Allen said.

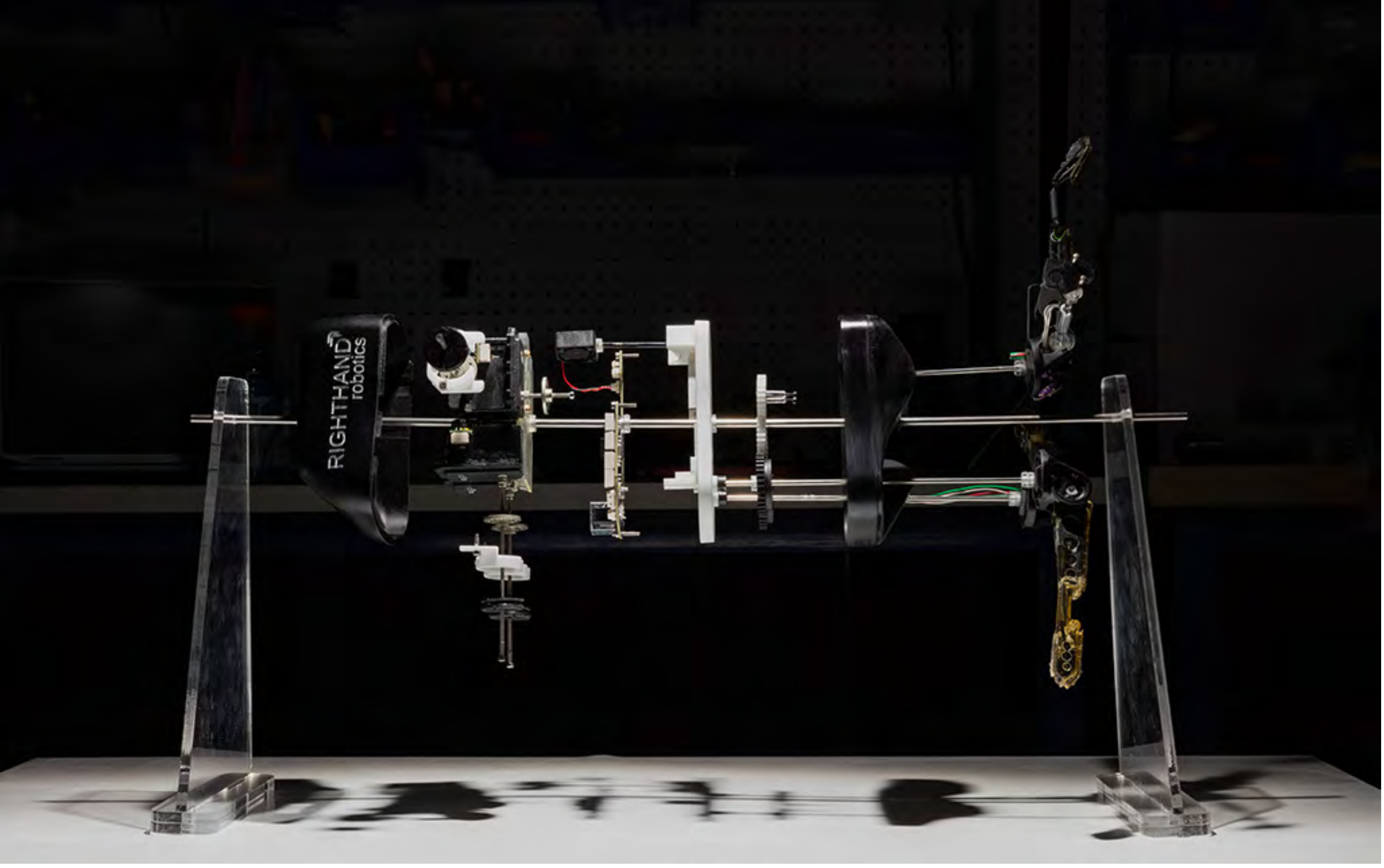
The 3D printed parts worked perfectly as substitutes for the electronic sub-assemblies. The process reduced the lead time for the PCBA inserts from three weeks to three days, and the cost per insert dropped from $100 to $0.80.

“It allowed us to intercept the process further down the line and save a bunch of upfront steps. Three or four upfront steps were just erased by doing it this way. It saved a bunch of time,” Beardsley said.

Because the printed parts were incredibly affordable to produce, the team was able to provide more than the factory had estimated they would need, ensuring they could run shots uninterrupted until they saw satisfactory results.

“The fact that we were able to shut the tool off on 3D printed material, hit it with that high-pressure injection, and not even have it flash, that’s a bit unique. Had we not had the Form 2, we would not have been able to pull this off,” Beardsley said.

“When we did move to a full product cycle, we were sure that it was going to work,” Allen said.



RightHand Robotics

INDUSTRY: Robotics
APPLICATIONS: Mold making

Creating rubber molds with designs only possible on a 3D printer. Small patch production runs of 20 units allow for customer feedback to rapidly be implemented into the next batch of products.

At RightHand Robotics, design iteration doesn't end once a product is shipped.

The ability to make changes to a product's design during the production process—agile manufacturing—makes it possible for engineers and designers to continuously improve final products.

Sarah Mendelowitz leads the RightHand Labs team within RightHand Robotics. Her counterpart is Kat Ely, designer at partner organization CLEAR design lab. We wanted to learn about their production process for the ReFlex Hand, and how both companies view 3D printing as an integral tool for successful, collaborative manufacturing.

RightHand Robotics makes robotic systems for order fulfillment in warehouses, and RightHand Labs is the department that sells hardware designed for people doing robotics research in universities. RightHand Labs is like a small manufacturing facility for hardware products; this is where the magic happens: everything from designing hardware, to manufacturing it, to support and sales.

CLEAR design lab fabricates all of the parts for the ReFlex Hand. They cast the fingers, knuckles, the palm and the back shell, and then some internal parts that go inside the mechanics.

Sarah and Kat have learned to work together to improve the manufacturing process, and their close relationship has been part of their success. If Kat finds something during production that needs to change, she can implement that idea by printing a new mold on the Form 2 or printing a new component that's being overmolded. Their combined expertise in design for manufacturing, molding, and production of plastics allows for quick iterations, with the hand design morphing based on tests and functionality needs.

Kat and Sarah work in the same town but not in the same office. Both have a Form 2, which enables them to easily work collaboratively and remotely. The two send files back and forth and print the files on their respective 3D printers. Video conferences often include printed models to better facilitate idea creation and sharing.

The team will produce at least 20 units that can actually sell, but in creating those 20 units, the team learns a lot. The findings from these units are used to make design iterations for the next batch of 20 units. Due to 3D printing of the molds and cores, small batch and short-run production processes of only 20 units are possible. This gives Sarah the flexibility to change designs without sinking a lot of cost into tooling. If engineers want to change something in the design, they have the flexibility to do so. If they want to change a part of the manufacturing process, they have the flexibility to do so as well. That leads to a better product because the team can make changes very quickly to keep the product on the cutting-edge, constantly improving as customer feedback comes in.

“Doing small batch production processes is part of our strategy for the ReFlex products because it's the kind of niche market and the customers that we have are looking for very specific things, and they're doing very specific research. We want to stay on the forefront of the kind of research that they're doing. And so, as their needs change, we can change our product to match them.”

As long as Sarah has customers in the research community generating ideas that they would like implemented, she is willing to work with them to make sure that they have a solution in hardware.

“If researchers don't have to spend the time working on hardware and designing new hardware, they can spend their time solving new research problems and new robotics challenges. The more affordable and cost-effective we can make our grippers, the more research will be able to be done in new areas that are even more exciting.”

Sarah also uses the Form 2 to do prototyping of components that are going into the ReFlex Hand and industrial systems; she believes that the Form 2 complements her approach because it's a tool that can move as fast as her design process. Being able to 3D print in-house means that that she doesn't have to wait on any external timeline to do prototyping; Sarah can go from CAD to a functional test within the same day.

Kat has been using 3D printing to make the fingers for RightHand Robotics. A 3D printed core and some electronics are stuck into a mold, and rubber poured around it. Then it gets stuck into a secondary mold and overmold around that. There's an internal channel that goes through the core of the finger for the wire that actuates the finger. Kat says she can only get that internal core through 3D printing; in her view, there's really no other way to manufacture that.

“I do really like the SLA prints because they have a really nice surface finish. For production, you want parts that look finished. For prototyping, you still want to look like production quality parts.”

Both RightHand Labs and CLEAR design lab use Form 2 3D printers in their production processes.

"That's sort of the whole idea behind the prototype, is that it should look like a final version. The prints come off the printer looking really nice, and then usually we sand them; they have a really nice quality to them that looks like an injection molded plastic."

Previously, Kat were outsourcing a lot of 3D printing because other 3D printers are so insanely expensive. "Having cheaper access to prototyping really changes the whole design process so that you don't have to get a design as locked down before you prototype it.

You can design something in SOLIDWORKS all day long and then you print it in a scale that doesn't feel right or the ergonomics aren't quite you were expecting."

"It really reduces the cost of product development, it makes it so that a lot of startups can exist that probably couldn't exist before because they just couldn't afford the cost of product development."

Nervous System

INDUSTRY: Jewelry
APPLICATIONS: Computer simulation ceramic Jewelry designs printed directly on a 3D printer.

Nervous System augmented the traditional ceramic process with a 3D printer to create a distinctive jewelry line.

Trial and error is in Nervous System's DNA. The generative design studio creates unique art, jewelry, and housewares through mash-ups of computer science, math, biology, and architecture and a process driven by testing the limits of emerging technologies and techniques.

Nervous System decided to launch their first-ever 3D printed ceramic product: "Porifera," a jewelry line fabricated with Formlabs Ceramic Resin. The product line came together in just a few months after the studio beta tested the latest formulation of the resin, but its genesis is rooted in years of experimentation with various ceramic materials.

Every Nervous System project is sparked by a different source of inspiration. Some are motivated directly by biology, beginning with computer programs that generate forms by mimicking natural processes, like how veins form in leaves. Other products are inspired by new fabrication techniques. This was the case for the Porifera collection.

"Ceramic materials are really beautiful and have nice qualities. They're inexpensive and strong, and they have this nice tactile feel; they can be glossy or more earthy," said Rosenkrantz.

The studio had previously outsourced the production of a porcelain housewares line, but was eager to merge the intricate geometries available with additive technology with the quality of traditional ceramics.

They tested a variety of powder-based and resin-based ceramic 3D printing materials, but the weight and feel of the resulting pieces were still too distant from traditional ceramics. While beta testing Formlabs formulations, Nervous System helped steer material development to cross some of these challenges, like printability issues and final fired part density.

“One of the things we’re most excited about is the ability to make objects you couldn’t make using any other ceramic technique,” Rosenkrantz said. “You can’t make super-thin interconnected three-dimensional structures. They can’t be cast. The green state of most ceramic processing is very fragile. But the green state of the 3D printing material is strong because it has resin in it. So we can make these super weird geometries that are super strong when they’re fired.”

> *“It’s nice to make things in-house,” Louis-Rosenberg said. “We don’t necessarily want to be tied to a technology. Making a huge investment into a tool is not something that we’re interested in, but being able to make things on our own and experiment is something we’re excited about.”*

Nervous System tested a range of concepts with Formlabs Ceramic Resin. Printability was paramount: the material is experimental and required intensive exploration to uncover the ideal geometries. They began with working on a tea set, but honed in on a smaller product after running into challenges printing the set’s cellular structures and maintaining cost-effective production.

“We knew that we wanted to work with a ceramic 3D printing material for a while, but we didn’t necessarily know what we wanted to make,” said Louis-Rosenberg. “A teapot and cups are very large, so it’s hard to make them affordable, so we’re still working on that project. We wanted to start with something smaller, like jewelry.”

3D printing ceramics allowed Nervous System to fabricate thin, unique geometries for their Porifera collection.

The thin, self-supporting structures of deep sea sponges were part of the inspiration for the Porifera collection. The sponges absorb silica from the surrounding water to form delicate glass skeletons.

Previous ceramic materials Nervous System worked with did not reach the density of traditional ceramics, so parts in their fired state were still very porous, and required a different glazing process.

“We would sort of fully fire them, then glaze them, and then do a low fire glaze,” Louis-Rosenberg said. “That doesn’t make sense for Formlabs Ceramic Resin, because it’s able to get more of a fully dense final part. This is what is good about it, but that means that if you fire it all the way, it’s very hard to glaze because the glaze doesn’t actually stick to a glassy surface.”

“What we do is actually much more like a traditional ceramic process; we first do this process, called a burnout where all of the resin is removed and we fire it to a lower temperature—1900 degrees Fahrenheit, which is around a cone of 05. That leaves kind of a very brittle, porous part. We want it to be porous, because that way it accepts glaze very well,” Louis-Rosenberg said.

“It’s weird. It doesn’t sound like to your head that there’s a lot of difference between 1900 Fahrenheit and 2350 Fahrenheit, but when you fire it to 1900 it comes up white and chalky. When you fire it to 2300 it comes out like glassy and smooth. So that’s where all of the big changes happen is in that weird zone,” Rosenkrantz said.

END-USE PARTS

Additive manufacturing has swiftly matured in the past several years, with advances in hardware, software, and resin expanding opportunities for the technology. 3D printing will enhance current work processes while increasingly being incorporated in more functional end-use parts. Concepts once thought unattainable, such as mass customization, can now be fully realized.

In the section, you'll meet leading firms taking the first steps towards using 3D printing in end-use functional parts such as razors, car parts, and shoes. This means moving away from only using 3D printing internally, and feeling comfortable sending products made of 3D printed materials directly to consumers.

The exact definition of a functional part varies for every business and situation. While the examples in this section are broad, they represent the diverse use cases available to teams who fully incorporate 3D printing.

Find out how:

Gillette took advantage of new avenues in mass customization introduced by 3D printing to give shoppers the ability to create their own razor handle online.

Ringbrothers an automotive shop creating custom cars, originally used 3D printing to test the fit, feel, and function for their custom parts, before moving on to printing functional parts for the car itself.

New Balance is using a custom resin to create high-performance athletic sneakers.

Gillette

INDUSTRY: Consumer Products
APPLICATIONS: Customized end-use parts

Implementation of 3D printing gave customers the ability to create and order customized 3D printed razor handles, a product Gillette had never offered before.

Razor manufacturer Gillette is at the forefront of offering more personalized products with its Razor Maker™ concept—a platform that serves as one of the first examples of direct-to-consumer, end-use 3D printed parts.

Using Formlabs 3D printers as its production engine, Razor Maker™ gives consumers the power to create and order customized 3D printed razor handles, with the choice of 48 different designs (and counting), a variety of colors, and the option to add custom text.

"Our partnership with Formlabs, and the power of their 3D printers, enable consumers to have a say on how their razors should look. We are excited to work with our Boston neighbors to pilot this breakthrough concept of customization," said Donato Diez, global brand manager for Gillette and Razor Maker™ co-founder.

"Combining our best shaving technology with the power and flexibility of 3D printing opens up a whole new world of product design possibilities," said Rob Johnson, design engineer and Razor Maker™ co-founder.

With 3D printing, complexity and variety are "free"; a 3D printer takes no more time, energy, or material to manufacture a complex shape than a simple one, and zero tooling means printing a variety of designs requires no extra production costs.

Through Razor Maker™, Gillette is able to offer thousands of consumers the power to design a handle unique to their lifestyle and preferences.

"It allows us to think about form in a way that was never possible before," said Rory McGarry, industrial design lead at Razor Maker™. "In a traditional sense, we could only do one or two razor designs a year, whereas now we can have an idea, create it in 3D, print it, look at it, adjust it, and say that's it."

Ultimately, the absence of design constraints fuels the ability to offer consumers freedom of choice. In a market saturated by mass-produced goods, the goal of Razor Maker™ is to offer consumers the chance to make razors that are completely their own.

The initial steps in the process are completely digital: a consumer customizes a unique handle through the Razor Maker™ website and the resulting design is converted into a 3D file. Multiple design files are then sent to a 3D printer to be simultaneously printed in a single batch. Each handle is then washed, post-cured, coated, and assembled before being shipped directly to a consumer's door.

Previously, Gillette had only applied 3D printing for prototyping, but advancements in materials and hardware have made the technology a viable option to produce end-use parts.

Ease of customization is an inherent advantage of 3D printing. The technology removes the need for tooling, requiring no up-front investment in molds and eliminating the exponential costs of producing a variety of complex designs. Plus, scaling custom manufacturing can be as easy as adding more printers.

"The Razor Maker™ concept allows us to create a new design, print and test it, and then the next day that design becomes a new handle available on the website," Johnson said. "That was never possible before."

New technology alone isn't enough to transform manufacturing. Companies like Gillette are leveraging 3D printing to explore entirely new business models that change the way they work across the entire product lifecycle, from design through production.

"For Gillette, piloting Razor Maker™ represents a crucial step in our customization journey where new technology and new business models must come together in order to deliver products that are as unique as our consumers," Diez said. The pilot program was highly successful for Gillette, and they expect to build on the Razor Maker program in the future.

Ringbrothers

INDUSTRY: Automotive
APPLICATIONS: Automotive 3D printed parts for final assembly

The team first invested in in-house 3D printing as a tool for expediting prototyping. Soon, other use cases emerged, including using casting a Cadillac emblem for a custom car.

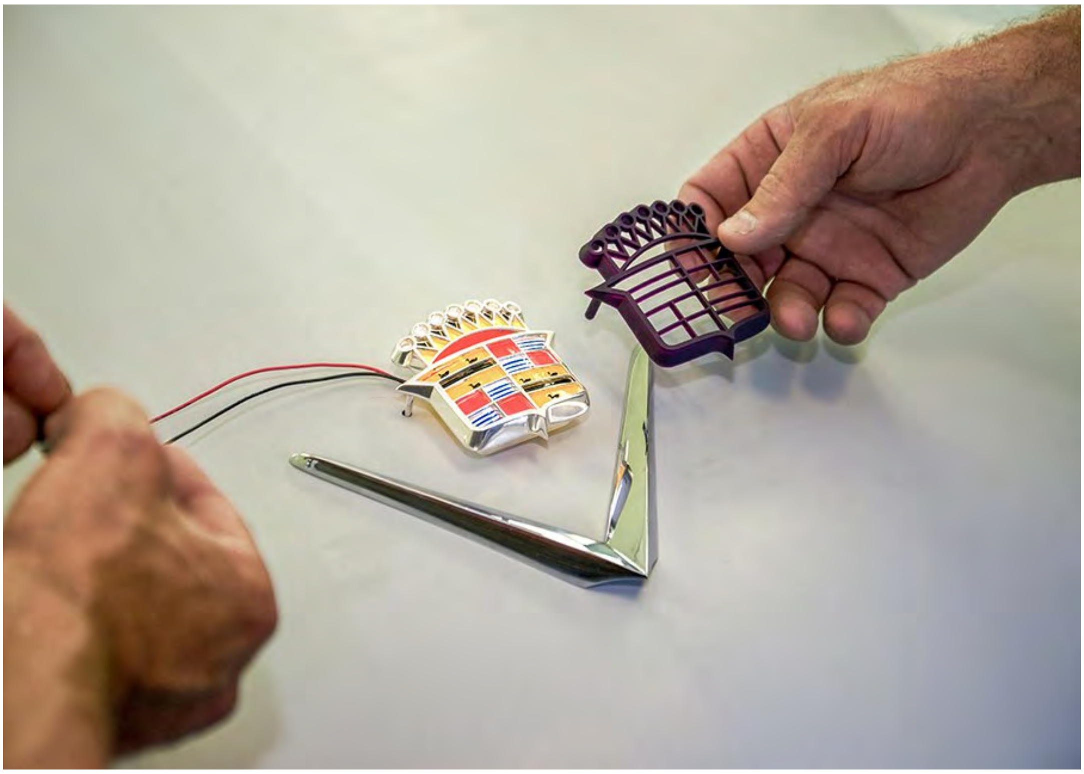
"Custom" is at the core of the Ringbrothers brand. The shop, co-founded by brothers Jim and Mike Ring, has made a name for itself by building award-winning custom cars and producing a line of high-quality, uniquely crafted billet accessories and fiberglass and carbon fiber pieces.

But creating unique products can be a challenge. Businesses must create novel designs and high-quality parts that set them apart from the competition while also balancing the cost of designing, testing, and manufacturing custom pieces.

As a product development specialist, Matt Moseman is familiar with the tradeoffs that come with the intent to create highly unique, high-quality parts and the need to keep costs down and move quickly. One of his goals is to help counteract these compromises.

3D printing has been a game changer in unlocking room to experiment with and perfect designs, instead of facing the compromises that come with the commitment of other expensive and time-intensive manufacturing processes.

"Nobody wants to say something's good enough, because you feel it in your stomach. I've already invested x thousand into this tool or in labor to get this far, and I really only want that small change done and nobody's ever going to know. Those compromises can really eat away when you do a large scale project," Moseman said.



The Ringbrothers team used Castable Wax Resin to 3D print and cast a Cadillac emblem for a custom car.

Moseman uses in-house SLA 3D printing to increase the cycles of iteration between digital design and machined part and shorten the distance between idea and final successful product.

One way Ringbrothers continues to stay ahead is vertical integration. Moseman has helped lead the charge on bringing in more technology in-house.

"The goal is to be able to serve our customers better and hedge against how we're seeing the industry change, because it's becoming far more common for people to be able to buy the three-axis vertical mills and introduce machining into their shops," Moseman said.

"Previously everything was outsourced; everything was contracted out for manufacturing, engineering, and all the design. While we still do work with a lot of contract designers, engineers, and machinists, but the more we can bring in-house the better we are, especially with the 3D printers, all our CNCs, and we're even updating to five-axis machines now," Moseman said.

In terms of weighing decisions for what technology to bring in-house and when, one of the considerations is balancing investments with tech maturity.

"As far as innovation goes for me, it's weighing if the product that's out there today is ready yet. Like metal 3D printing, I mean I'd love to have them, but I don't personally feel like it's there at a reasonable enough price for somebody at our size. It's definitely on our radar in the future, but it's just not in our future right now because we just financially can't swing that," Mike Ring said.

While in-house 3D printing started as a tool for expediting prototyping, the team quickly saw opportunities for using 3D prints in other ways.

> *"The industrial design aspect of trying to get the visual—that's what really the printer started as. But, as you start using them, you realize this material is actually tougher than you expected and holds a lot better properties. Why can't we make pieces that are going to live on that vehicle forever that came off a printer?" Moseman said.*

The Ringbrothers team brought SLA 3D printing in-house as a prototyping tool and have since found ways to leverage the technology to produce end-use parts.

For a mirror project, the team used 3D printed parts as part of the final assembly; the part acted as a permanent assembly fixture bonded inside a carbon shell that additional parts are bolted onto.

“Had we machined that part, it would have been really cost-prohibitive,” Moseman said.

In another case, the team used Formlabs Castable Wax Resin, to create an emblem for a custom car project.

“We found the opportunity to make an emblem that wasn’t really suited to be machined out of aluminum. It could have been done, but by the time you chrome that and match it to the rest of the exterior of the vehicle, a lot of the detail would have been lost in that emblem. And, knowing the customer and knowing the level of what he really wants in the vehicle, we just knew he wouldn’t have been happy,” Moseman said.

“That next level detail wouldn’t have been possible had we not been able to 3D print the wax and have [our local jeweler] cast it in-house.”

“I think everybody’s going to be excited when they see what’s in store, because we’re really going to be trying to push the envelope for 2019,” said Jim Ring. “It’s going to be a completely digital car.”

“To get to that, it was tough to accept that we had to take a slower year to kind of build up, get all that in the works. But then, it also goes back to getting the architecture of the rest of the business ready for that. I’ve been focusing with the team that we have and really bringing all the products that we have under our roof and streamlining. We’ve got a lot of work ahead of us.”

New Balance

INDUSTRY: Footwear
APPLICATIONS:
High-performance shoes

New Balance partnered with Formlabs to create Rebound Resin, a versatile new material. Rebound Resin was used to launch the 990 Sport Triple Cell, an athletic shoe with a 3D printed heel.

Key performance is in the details. In footwear, that means design and materials—both of which are ultimately bound by manufacturing.

In 2017, New Balance began a partnership with Formlabs to develop a 3D printing production system to open innovation opportunities on both fronts, with unlimited design freedom to create performance-optimized structures, an avenue to affordably manufacture customized components at scale, and a new arena of material possibilities.

In the summer of 2019, the company took a giant step forward in delivering on this vision with the announcement of TripleCell: a premium technology platform powered by Formlabs SLA 3D printers and a completely new material, Rebound Resin. Within the first year of being announced, two shoes containing 3D printed components were released under this technology platform: the 990 Sport Triple Cell and the FuelCell Echo Triple.

Shoes are inherently complex products. Footwear is a high inventory, high volume business that often still involves a lot of manual labor and craftsmanship. New Balance introduces thousands of designs a year, and a single model includes hundreds of SKUs of color and size combinations, with components made with different materials, tolerances, and tooling programs.

As the demand for customization grows, this only becomes more complicated. The modern consumer demands custom products that can be ordered from anywhere, from a variety of devices, and quickly delivered.

In addition to collaborations with professional athletes, New Balance has used 3D printing for prototyping for quite a while. Today the company produces thousands of 3D printed prototypes each year. As the 3D printing market matured, they were watching.

“We saw innovation with 3D printers and materials and started to envision the future of how this could come together in consumer products,” Petrecca said.

“When you’re able to use techniques like 3D printing to turn to more of an on-demand manufacturing model, that’s a game-changer. There are advantages both for the consumer and for New Balance as a manufacturer. On the consumer side, the ability to design and what you can fabricate with printing is well beyond what we can do with molding. It really opens up a lot of opportunities for us to make better parts than we’re making now with foam and plastic.”

The majority of the foam components in today’s footwear are manufactured through variations of injection or compression molding, which tremendously limits design possibilities. Transitioning to using 3D printing for both prototyping and production, however, has opened up new opportunities impossible with traditional manufacturing processes.

“What we could do to date is to engineer the outside of the shoe and rely on the inherent properties of the material to provide all the performance benefits we’re looking for. Any degree of what you could consider customization is disparate pieces of foam glued or molded together, with a lot of assembly steps on the back end,” said New Balance Senior Additive Manufacturing Engineer Dan Dempsey. “Using additive manufacturing, we can essentially vary the lattice structure to really change localized properties inside of a single form, giving us the ability to engineer throughout the entire volume of the shoe; we can design a system from the inside out.”

Rebound Resin is designed to create springy, resilient lattice structures and has a much higher energy return, tear strength, and elongation than any other Formlabs SLA material.

This new way of designing opens up a completely new level of performance possibilities. And that's exactly what TripleCell accomplishes: seamless tuning of the entire underfoot, enabling a high cushion zone to transition to an area of high stability within one design, and one material.

Prototyping and manufacturing parts with 3D printing also transform the entire product development workflow, significantly reducing time to market.

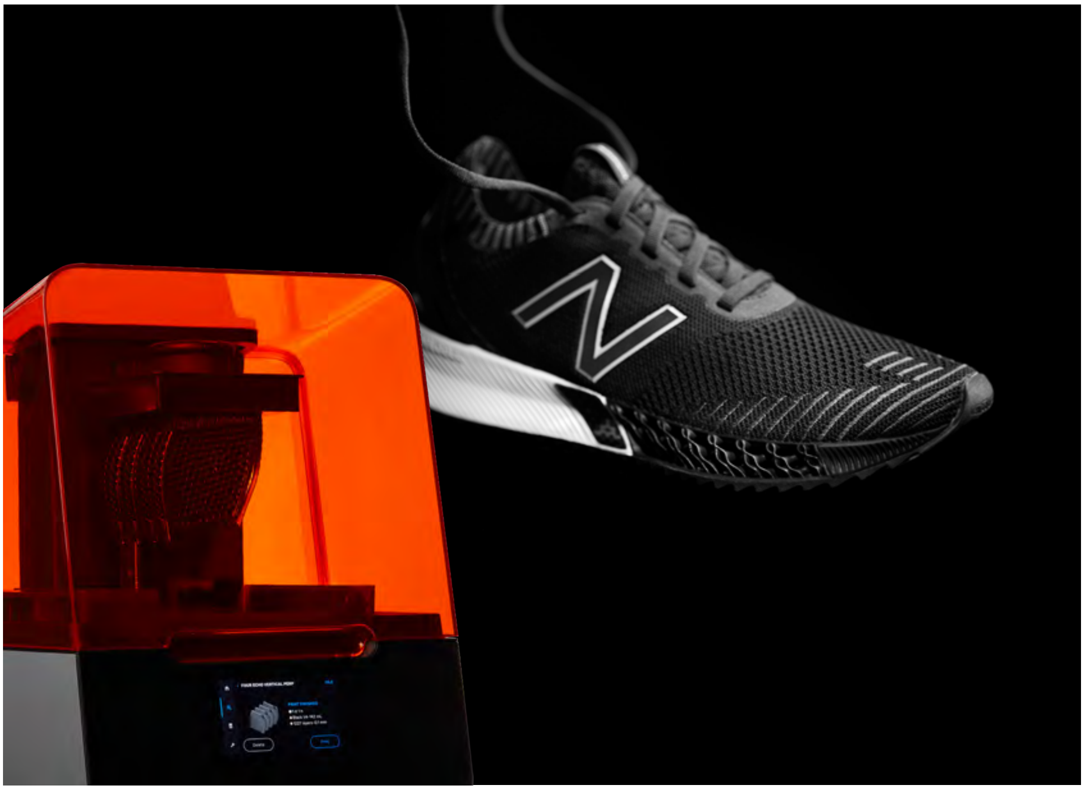
"The traditional timeline for our product cycle from paper initiation to delivery in market is 15-18 months. And when we're building tools and waiting for foam or rubber parts, we're looking at 4-6 week lead times." Petrecca said. "By eliminating molds, we can save months of development time. TripleCell technology makes it possible to easily produce multiple designs at the same time, reinventing the traditional iterative testing approach. We had the ability to generate and edit thousands of options before landing on the high-performance, running focused structures you see today."

The TripleCell collaboration marks another milestone in 3D printing applications expanding from prototyping into production at scale.

This cutting-edge digitally manufactured technology is now scaling exclusively within New Balance factories in the US. Next year, New Balance plans to scale up production to over 10,000 pairs per year of TripleCell products and continue growth within their manufacturing facilities.

Moving forward, TripleCell provides the foundation for leveraging unique athlete data and performance insights to create custom footwear in limitless combinations, and produce it on-demand, reducing development timelines and condensing the delivery from concept to consumer.

"Where we are now is just a testament to the work we've done in-house and the external partnership with Formlabs that have really been able to move our program forward," Petrecca said. "We've demonstrated that we are able to scale up additive manufacturing and have it make sense for a production environment. As far as where we go next, the sky is really the limit."



The FuelCell Echo Triple moves Rebound Resin to the forefoot, utilizing the unique lattice structure to boost performance during athletic activity.

ANYONE CAN CREATE ANYTHING

Desktop 3D printing empowers engineers and product designers to rapidly prototype in-house, cut costs, decrease production times, create unique molds, explore new concepts and much more. This e-book highlights only a few selected use-cases of 3D printing success; there are thousands of printers being used across the manufacturing and engineering industries. We hope you found inspiration from our users and have a better understanding of how 3D printers are changing traditional engineering and manufacturing workflows.