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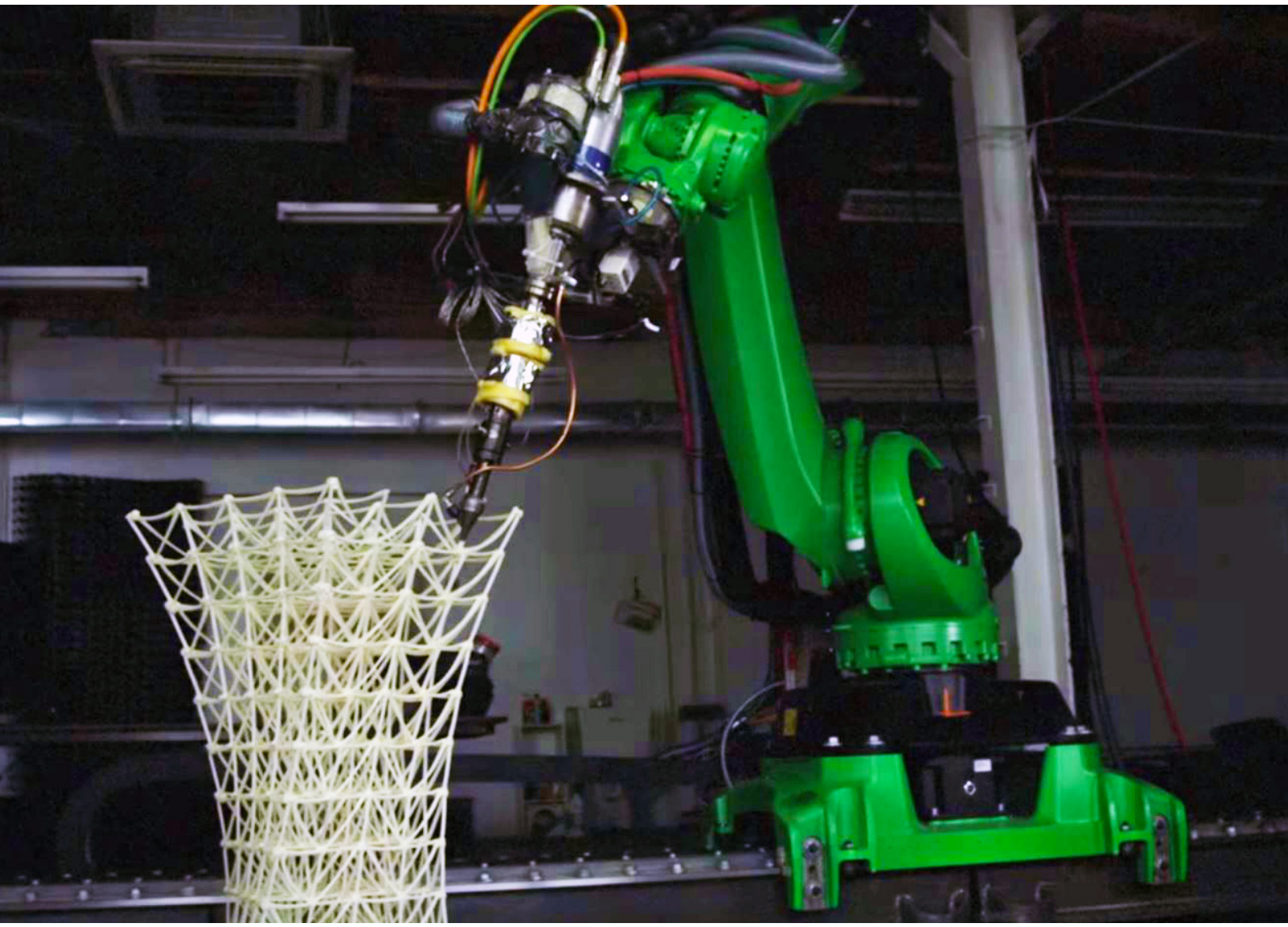

Why Additive Manufacturing and 3D Printing Benefits Robot Creators

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WHY ADDITIVE MANUFACTURING AND 3D PRINTING BENEFITS ROBOT CREATORS

As new materials, companies and processes emerge, the disruptive ability of 3D printing can save robot creators time, money, and create better designs and fabrication of robots for years to come.

By Jim Romeo

While many robotics companies already utilize 3D printing in the designs of their robots, experts say this relationship will grow as the benefits of additive manufacturing gains more recognition as a smart manufacturing practice for production as well.

The flexibility and customization that 3D printing creates will be more widely adopted by companies in the months and years to come. Both technologies – additive manufacturing/3D printing and robotics – complement each other to achieve positive results, which get passed on to customers with a better and more effective robot.

DISRUPTING INDUSTRIES WITHIN MANUFACTURING

In 2018, consultancy McKinsey and Company published "The Next Horizon for Industrial Manufacturing: Adopting Digital Technologies in Making and Delivering," which summarized the importance of disruptive technologies and their impact on industrial manufacturing.

"In the past few years, advanced industrial companies have made solid progress in improving productivity along the manufacturing value chain. In the U.S., for instance, the productivity of industrial workers has increased by 47% over the past 20 years. But the traditional levers that have driven these gains, such as lean operations, Six Sigma, and total quality management, are starting to run out of steam, and the incremental benefits they deliver are declining. As a result, leading companies are now looking to disruptive technologies for their next horizon of performance improvement."

Two of those disruptions named in the McKinsey report were additive manufacturing (3D printing), and robotics. The intersection of both

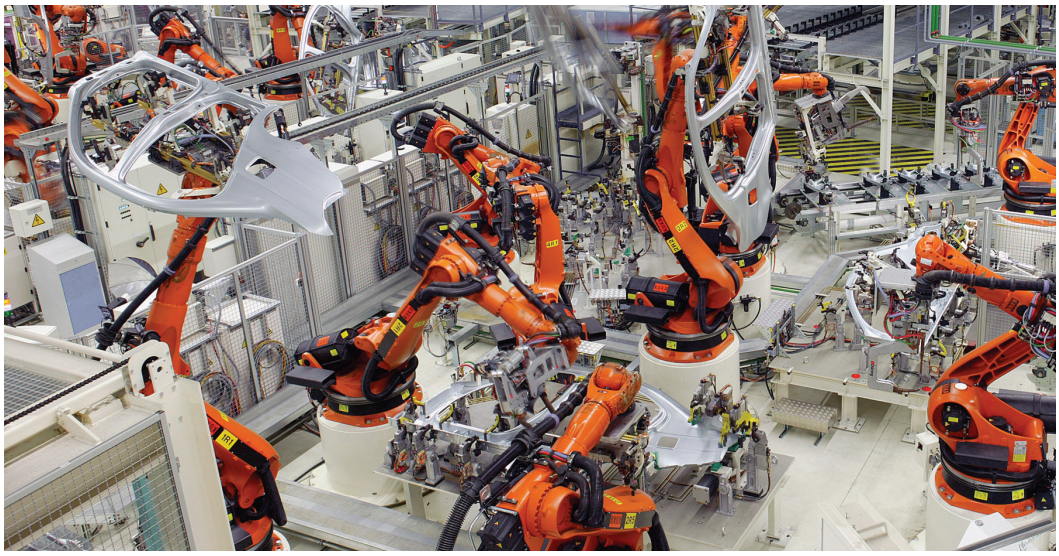
technologies, combined, present a newfound potential for robotics companies and their customers.

Using 3D printing in the creation of robots not only improves their technology; many experts we talked with said it makes them better, smarter, more useful, and agile. It allows engineers and technology leaders who create robots to advance their remarkable technology and achieve the goals of their customers and users.

Research firm IDC said trade wars and manufacturing automation will drive more than 40% of discrete manufacturers worldwide to implement 3D printing by 2021. By then, 40% of the top 2,000 manufacturers will utilize 3D printing, combined with intelligent machine tools, to optimize material usage, thus reducing waste by at least 25%. This portends a smarter way to build a better robot.

3D PRINTING AND ADDITIVE MANUFACTURING FOR ROBOTICS: AN IDEAL COMPLEMENT?

KUKA Robotics, a German manufacturer of industrial robots, knows well that a robotics application for one industry may have different requirements for another industry. Thus, they have a comprehensive catalog of product offerings with custom tool options. That may be part of the reason why additive manufacturing is ideal for the robotics industry. Robotics engineers are forever seeking more versatility, performance, and accuracy. Additive manufacturing aids prototyping, tooling, fabrication, while lowering cost and time-to-market – and helps robotics engineers achieve their goals.



KUKA Robotics provides custom tool options for industrial robot customers, making additive manufacturing an interesting and required option for parts and tools.

Using rapid prototyping made possible by 3D printing, for example, KUKA says they can customize designs for robotic applications according to customer requests – and refine their designs based on testing and trial. The company says it's been a boon for them, and many other technology developers in other industries as well.

"Traditionally, 3D printing was primarily used for prototyping, but now we see that it's ready to hit the production floor," says Joe Gemma, Chief Robotics Officer at KUKA Robotics. "Additive manufacturing has numerous benefits across a multitude of industries: It can accelerate product design and time to market, reduce costs and waste, and increase flexibility creating more complex designs. It's the latter of these features that is the most intriguing. For the first time, we have the ability to mass produce customized products for customers. With the push for more personalization, this is a huge development in the manufacturing space."

NEW TOOLING FOR ROBOTICS MANUFACTURERS

Additive manufacturing is already used in mainstream manufacturing to create tools, jigs, and fixtures to produce complex products better. For the robotics industry, the customization of parts, fitted for a specific task, is an essential fixture within their landscape. Robots aren't always engineered and manufactured as like-kind machines. They are more often customized to a specific need. They often replace tasks that are "dirty, dull, or dangerous" for humans, and their value-add is derived when they perform specific functions that were previously accomplished by a human.

Cullen Hilkene, CEO of 3Diligent in El Segundo, Calif., says 3D printing has been used extensively in recent years to achieve the performance and specific functions, enabling custom robotics development. "Because different robots have different operational requirements, 3D printing's ability to create custom parts uniquely suited for the task – and the ability to print in materials that will hold up – has been big," he says.

Cullen Hilkene, 3Diligent

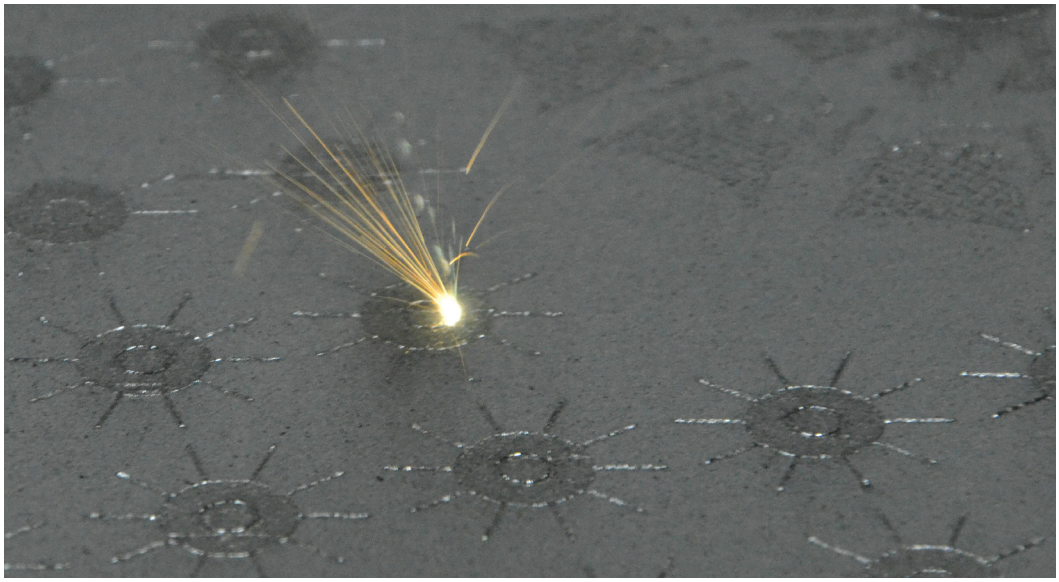
Making custom parts demonstrates how 3D printing and additive manufacturing have different uses for

different industries. Just as manufacturing uses 3D printing and additive manufacturing to create jigs, tools, and other fixtures used in the production process, the robotics industry can use 3D printing as part of their engineering design process and to tool and fabricate their designs.

Customization gives options for robotics engineers who, like KUKA, are always designing to a customer demand. With 3D printing, robotics designers can integrate with other machining and tooling processes.

"Additive manufacturing opens doors for a range of applications within the robotics industry," says John Dulchinos, vice president, digital manufacturing at Jabil, Inc. "Design engineers can quickly print tooling and fixtures for the robotic assembly process on 3D printers. Another application is leveraging Design for Additive Manufacturing (DfAM) to consolidate the Bill of Materials (BOM). An example could be designing a gripper that integrates the hoses into the design and connects to the vacuum. The uses of additive manufacturing for the next generation of robotics is endless."

Dulchinos says DfAM lets engineers and designers create parts without molds, and design unique geometries that aren't possible with traditional manufacturing methods. Additive manufacturing can also help reduce a robot's weight and mass, which makes it stronger, move faster, and use less energy. Designers can develop several iterations quickly to determine the best product design to take to full-scale production. Streamlined designs with fewer, or lighter parts, can help optimize the overall design as well.



An example of parts that were 3D printed by Sigma Labs

"Differing and initially unrelated advanced manufacturing technologies frequently converge with each other to develop optimized hybrid machinery and processes," says John Rice, CEO and chairman of Sigma Labs Inc. in Santa Fe, New Mexico. "As a company involved in 3D metal manufacturing, we see 3D technology benefitting the robotics industry by allowing designers to use 3D design and manufacturing technology to significantly reduce the number of individual parts in a robotics assembly in the same way that General Electric cut the number of parts in one of its turboprop engines by 35% by combining assemblies of multiple parts into a single part manufactured by 3D printing. Adopting 3D manufacturing to robotics in this way, potentially bolstered by in-process quality assurance technology, has the potential to reduce cost, reduce waste of raw materials, and increase durability by eliminating potential failure points of part junctions."

RAPID PROTOTYPING

For robotics design, 3D printing is ideal for rapid prototyping. Designing robotics requires a lot of trial and error. This begins with a concept and different design parameters that are used to meet an intended application or routine. Prototypes may be developed quickly, inexpensively, and with little overall risk, through a 3D printing process.

An aircraft part fabricated from 3D printed prototype by Fab Lab Hub.

"A 3D-printed prototype can be created in a fraction of the time it takes to machine a part," says Sarah Boisvert, founder and CEO of Fab Lab Hub in Santa Fe. "However, speed is reversed when moving to production

where machining, injection molding, etc. are much faster than 3D printing. HP is saying its new production machines are competitive with injection molding at about 100,000 parts, which is better than the early days but still not a cost-effective method to make 100 million copies of the same part."

Minimizing production time, and the ease of low-volume production associated with the rapid prototyping, provides an uncanny flexibility in making robotic machines. Expedient prototyping is a strategic advantage, helping robot manufacturers better compete in a market that moves at lightning speed.

Andrew Edman, Formlabs

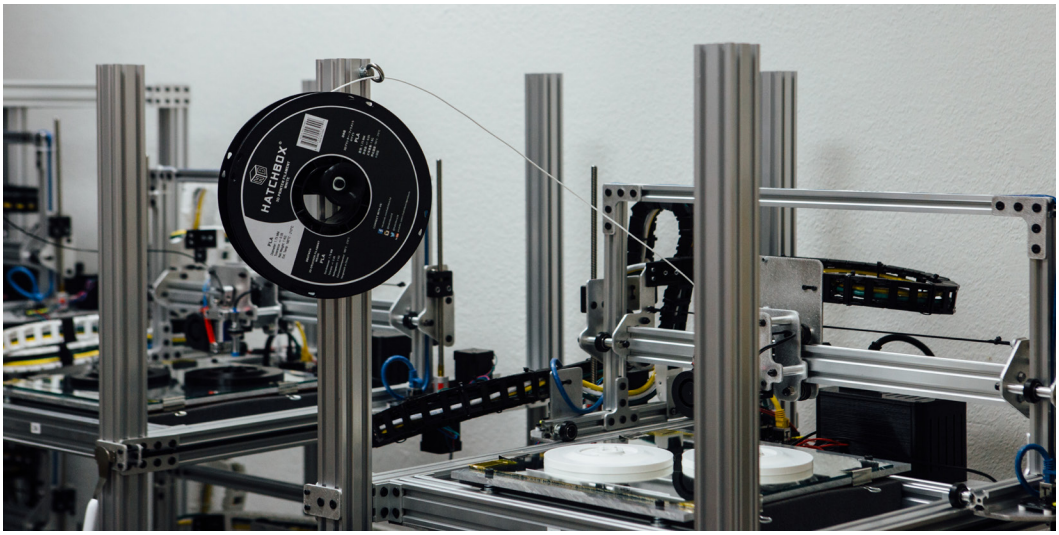
"Part geometries for robots are often complex, and costly to produce with traditional manufacturing processes," says Andrew Edman, industry manager for product design, engineering and manufacturing at Formlabs in Somerville, Mass. "Additionally, a robot product may be developed to serve a very specific market application, like inspecting oil and gas pipelines. For those markets, overall volume needs can be low, making injection molding or even machining costs prohibitive. Ultimately, leveraging additive manufacturing gives engineers more flexibility to build the best robotic mechanisms and products from start to finish."

RightHand Robotics used Formlabs to create some early robot prototypes.

DIRECT FABRICATION

3D printing isn't just used to produce tooling and fixtures, or for prototyping. It is quite feasible that 3D printing could fabricate the robot itself - or at least many of its components.

"We're seeing more and more robotics and robotics parts being 3D printed," says Jared Go, CTO and co-founder of OhmniLabs in Santa Clara, Calif. "There is a lot of diversity in 3D printed materials, and that enables more creativity, duration and use cases."



3D printing parts for its robots is a big part of how OhmniLabs can produce less expensive robots.

He adds that 3D printing is not just a substitute for injection molding, but should be seen as a different way to build products. "Everyone in the robotics industry should know that you can get very creative with 3D printing, from parts to wiring," he says. "The potential is massive, and will allow the industry to move quicker with more control than utilizing injection molding."

Direct fabrication via additive manufacturing offers many economic benefits to the development process. In their report "How Industrial and Technology Giants Can Set the Service Pace," consultancy Bain & Company cites pump manufacturer Sulzer's use of additive manufacturing in conjunction with traditional milling to quickly produce and improve pump impellers (the rotating part of the pump that moves the fluid). A few years ago it took them 10 weeks to produce impellers, but now they can make them within 48 hours of ordering with the new process.

"Over the next five years, there will be many more such examples as 3D printing alters the flow of parts and the economics of parts makers and

OEMs," Bain authors said in their report. "This has already started for spare parts that are low in volume, high in value, complex in design and for which delivery is time critical."

"In addition to developing better tooling, leveraging design freedoms, customizing robots, and getting to market faster, using additive manufacturing the robotics industry can also take advantage of producing smaller volumes with no upfront costs," says Jabil's John Dulchinos. "Since molds are not required with additive manufacturing, low-volume builds can be profitable. This, along with the multitude of applications 3D printing can provide to the robotics industry, makes for a very innovative future."

SAVING TIME AND MONEY

Part of our innovative future is supported by the economics of 3D printing. "Know that the price points and the capabilities keep improving, such that more and more companies are finding that there's a reasonable business case to utilize 3D printing," says 3Diligent's Cullen Hilkene. He says additive manufacturing is better at meeting the sometimes-austere demands of the robotics industry.

"Within metal printing, performance generally matches or exceeds cast parts," Hilkene says. "Within polymers, it's more process dependent, but a number of processes can deliver parts with properties on par with injection molded parts. Still, also know that it takes the right application for 3D printing to win out over traditional technologies when it comes to higher volumes. Consider especially complex parts or sub-assemblies that might be combined into a single, highly complex part as ideal candidates for 3D printing production. The biggest wins for companies happen when they consider 3D printing's abilities to deliver unique geometries to fundamentally improve performance, not just achieve the same performance more cost effectively. An example of this might be lightening the weight of a robot through 3D printing's ability to easily create hollow or partially hollow parts with scaffolding, allowing for efficiency savings."

While the benefits of direct fabrication using additive manufacturing save time and cost – which helps make robotics fabricators and developers more competitive - they allow the robotics firm to focus more resources on research and development and innovating technology. Time and cost

savings from production gains can be directed elsewhere and subsequently pay dividends.

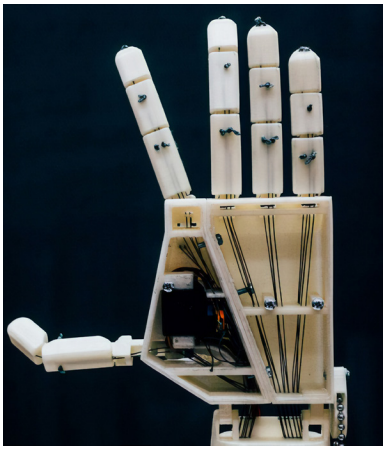
"Most people said that 3D printing can only be used for rapid prototyping and not for production, but we've been heavy users of additive manufacturing technology for the past five years and are absolutely sure about the engineering and economics," explains OhmniLabs' Jared Go. "Our internal manufacturing costs for quantity one of a whole new human-scale robot design at OhmniLabs can be 1,000 times cheaper than traditional molding costs – usually as much as $100,000 to $200,000. Our turnaround time internally for additive manufacturing is less than 24 hours, whereas involving an external vendor for injection molding often takes two to six weeks."

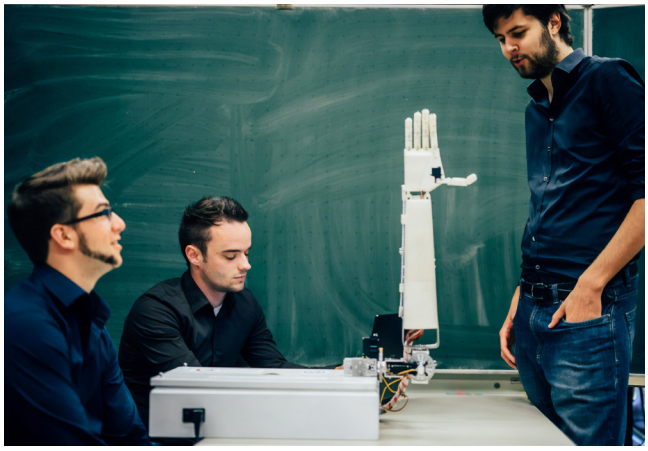
Stephen Lloyd, founder and operations director at U.K.-based OmniDynamics, concurs. He says the prospect and potential of 3D printing is a technological asset to fabricate robotic parts and finished products.

"There are false assumptions that you can only print in certain materials, only for certain prototypes, only at certain quantities, but actually you can utilize 3D printing for low volume batch production, Lloyd says. "Studies have shown that in most cases, if you're manufacturing 1,000 units or less, 3D printing is actually more cost-effective because of the high cost of injection molding. It makes 3D printing a very viable alternative. For robotics specifically, 3D printing is designed for lightweight custom builds, and that is exactly what most robotics prototypes need. You can't always buy in the parts that you need for a testing prototype, and getting it machined massively increases cost and time."

Part of what makes it a viable alternative to direct fabrication, stems from the design flexibility that 3D printing affords. Alkaios Bournias-Varotsis, Ph.D., is a technical content engineer with 3D Hubs B.V. in Amsterdam, Netherlands. He says 3D printing is welcome technology for today's robotics engineers, who are always seeking design flexibility. 3D printing, with its flexible feedstocks and an ability to incorporate even complex designs quickly, perfectly meets their desire for flexibility.

For example, he cites the need for organic forms – particularly for manufacturing robots – as they often perform the tasks of one or more humans. Thus, organic forms are needed, but can be complex and difficult to design for.





Creators at 3D Hubs create robotic hand parts via 3D printing.

"Soft robotics and custom grippers are another great application for 3D printing," says Bournias-Varotsis. "Here engineers take advantage also of a wide range of available materials. For example, flexible thermoplastic polyurethane (TPU) can be used to 3D print pneumatic grippers that would be very expensive or impossible to manufacture with any other process. In both cases, the development costs are also kept to a minimum since 3D printing is excellent for custom part production and prototyping."

NEED A PART? PRINT IT!

While custom part production is an advantage for robotics manufacturers, 3D printing can also be useful to repair robots. Replacement parts and spares can be created on demand. They may be reverse engineered and improved on to fix parts and designs that don't work. With a nearby 3D printer, a replacement part need not be ordered. It can be made on-site. This just turbocharges the entire supply chain as well as the maintenance and repair of robots. This benefit can be shared with other equipment as well.

KUKA's Joe Gemma says additive manufacturing makes repairs in the field of new and old equipment easier and more likely than in the past. "The probability of producing obsolete components for an old machine is now a reality in many cases," Gemma says. "Of course, it is still dependent on materials available, but more and more are being developed. Even new machines can benefit by quicker delivery of part replacement, possibly even produced on site. Finally, difficult-to-access locations, like an oil rig in the middle of the Gulf [of Mexico], could print a unique part to avoid emergency conditions."

3D PRINTING AND ITS INNOVATIVE FUTURE FOR ROBOTICS

The total offering of additive manufacturing is a welcome addition and part of the larger innovative future of robotics. This innovative future is driven by the very specific benefits it provides to end-to-end design, prototyping, and ultimately fabrication of robots and robotic parts.

John Dulchinos of Jabil summarized the benefit of additive manufacturing for robotics, now and into the future, when he says:

"In addition to developing better tooling, leveraging design freedoms, customizing robots, and getting to market faster using additive manufacturing the robotics industry can also take advantage of producing smaller volumes with no upfront costs. Since molds are not required with additive manufacturing, low volume builds can be profitable. This along with the multitude of applications 3D printing can provide to the robotics industry makes for a very innovative future."

PLAYERS IN THE 3D PRINTING MARKETPLACE

Here is the list of the major players in the 3D printing and additive manufacturing landscape, as of March 2019:

Players in the 3D Printing Marketplace

Name	Website	HQ / Location	Description
3D Hubs	www.3dhubs.com	Amsterdam, Netherlands, with locations worldwide	Online marketplace for 3D printing services and contract manufacturing.
3Diligent	www.3diligent.com	U.S. (El Segundo, Calif.)	Rapid manufacturing services provider, offering CAD/CAM-based fabrication services, including 3D printing, CNC machining, casting, and injection molding.
3D Systems Corp.	www.3dsystems.com	U.S. (Rock Hill, S.C.)	3D products and services, including 3D printers, print materials, on-demand parts services and digital design tools.
AIM3D	www.aim3d.de/en/	Germany (Rostock)	Spinoff from the University of Rostock with the aim to reduce the cost of additive manufacturing of metal parts.
Arcam AB	www.arcam.com	Sweden (Mölndal)	A division of GE Additive, Arcam provides cost-efficient additive manufacturing solutions for the production of metal components. Partners with manufacturers of orthopedic implants and aerospace industries.
Arevo Labs	www.arevo.com	U.S. (Milpitas, Calif.)	Delivering the future of composite manufacturing through advances in software, materials, and robotics. Enables the 3D printing of large, mass-produced parts and structures.

Players in the 3D Printing Marketplace

Name	Website	HQ / Location	Description
Carbon	www.carbon3d.com	U.S. (Redwood City, Calif.)	The world's leading digital manufacturing platform, reinventing how polymer products are designed, manufactured, and delivered, towards a digital and sustainable future.
Chromatic 3D Materials	www.c3dmaterials.com	U.S. (Golden Valley, Minn.)	Developing the technology to print with thermosets, a broad class of materials including polyurethanes, silicones, and epoxies.
Concept Laser GMbH	www.concept-laser.de/en/home.html	Germany	One of the world's leading providers of machine and plant technology for 3D printing of metal parts. Since December 2016, a part of GE Additive.
Desktop Metal	www.desktopmetal.com	U.S. (Burlington, Mass.)	Reinventing the way engineering and manufacturing teams produce metal parts – from prototyping through mass production.
Digital Alloys	www.digitalalloys.com	U.S. (Burlington, Mass.)	Providing the technology and expertise manufacturers need to metal additive manufacturing in production – enabling them to save time, shrink costs, and produce valuable new products.
Digital Mechanics Sweden AB	https://digitalmechanics.se	Sweden (Västerås)	Leading innovator in smart additive 3D production. Offer customers in the manufacturing industry access to a digital factory for rapid production of complex parts in plastic and metal.
DyeMansion	https://dyemansion.com/en	Germany (Munich)	Offers finishing systems that turn 3D-printed raw parts into high-value products, including precision coloring and high quality finishes for the most exact specifications.
Envision TEC GmbH	https://envisiontec.com	U.S. (Detroit)	Global provider of professional-grade 3D printing solutions. Develops, manufactures and sells 3D printers and proprietary materials worldwide.
EOS GmbH Electro Optical Systems	https://www.eos.info/en	Germany (Krailling)	Producer of systems for the additive manufacturing of components in metal and polymers, enabling customers to produce high quality products based on industrial 3D printing technologies)
Essentium	https://essentium3d.com	U.S. (College Station, Texas)	Provides industrial 3D printing solutions to disrupt traditional manufacturing processes by bringing product strength and production speed together, at scale.
ExOne Co.	https://www.exone.com	U.S. (North Huntingdon, Pennsylvania	Publicly traded manufacturing technology company, providing 3D printing machines, 3D printed products and related services to industrial customers in multiple segments, including pumps, automotive, aerospace, heavy equipment and energy.
Fab Lab Hub	http://fablabhub.org	U.S. (Santa Fe, New Mexico)	3D printing, laser cutting, and other digital fabrication for STEM education, innovation, startup creation, job creation and training.
Formlabs	www.formlabs.com	U.S. (Somerville, Mass.)	Formlabs is expanding access to digital fabrication, so anyone can make anything; the professional 3D printer of choice for engineers, designers, manufacturers, and decision-makers around the globe.
Fortify	https://3dfortify.com	U.S. (Boston)	Digital composite manufacturer. Through its patented Fluxprint technology, Fortify's process combines magnetics and digital light processing 3D printing to produce composite parts with ideal mechanical properties.
Glowforge	https://glowforge.com	U.S. (Seattle)	Creator of the 3D laser printer, the Glowforge wireless desktop laser makes it simple for designers, artists, and makers to take products directly from digital design to reality. Uses subtractive technology to cut and engrave products from materials like wood, leather, acrylic, paper, fabric – even chocolate.

Players in the 3D Printing Marketplace

Name	Website	HQ / Location	Description
HP	https://www8.hp.com/us/en/printers/3d-printers.html	U.S. (Palo Alto, Calif.)	HP is working hard to enable new materials innovations that break down some of the traditional barriers to 3D printing adoption—cost, quality, performance, and diversity. We're doing this through a growing portfolio of HP-branded powders and an open platform model that encourages third-party collaboration and materials expansion.
Markforged	www.markforged.com	U.S. (Watertown, Mass.)	Markforged transforms manufacturing with the most affordable 3D printers capable of producing parts tough enough for the factory floor. Engineers, designers, and manufacturing professionals all over the world rely on Markforged metal and composite printers for tooling, fixtures, functional prototyping, and high-value end-use production.
Materialise NV	www.materialise.com/en	Belgium (Leuven)	Creates a range of software solutions and 3D printing services to form a backbone for the 3D printing industry.
Morf3D	www.morf3d.com	U.S. (El Segundo, Calif.)	Provides a variety of fully integrated additive design and manufacturing services, including conceptualization, parameter optimization, metallic 3D printing, finishing, metallurgical examination, certification, and data analysis.
Nano Dimension	www.nano-di.com	Israel (Ness Ziona)	Leading provider of additive electronics, disrupting the way that cognitive, connected electronic products are made.
Proto Labs Inc.	www.protolabs.com	U.S. (Maple Plain, Minn.)	Rapid prototyping and on-demand production in as fast as one day.
RIZE	www.rize3d.com	U.S. (Boston)	Next-generation additive manufacturing company, creator of the RIZE ONE hybrid 3D printer and XRIZE, a full-color desktop industrial 3D printer.
Shapeways	www.shapeways.com	U.S. (New York)	Consumer 3D printing service, with a community of more than 1 million creators printing more than 10 million products.
Sigma Labs	www.sigmalabsinc.com	U.S. (Santa Fe, N.M.)	Software company that develops and commercializes real-time computer aided inspections solutions known as PrintRite3D for 3D advanced manufacturing technologies.
Sisma SpA	www.sisma.com		Designer and producer of innovative systems and solutions for those who manufacture and create, using precision micro mechanic systems, lasers up to 1kW of power, additive manufacturing, and other processes.
Stratasys Ltd.	www.stratasys.com	U.S. (Minneapolis) and Israel (Rehovot)	Global leader in additive manufacturing and 3D printing technology, maker of FDM and PolyJet 3D printers.
Voxeljet AG	www.voxeljet.com	Germany (Friedberg)	Manufacturer of industrial 3D printing systems.