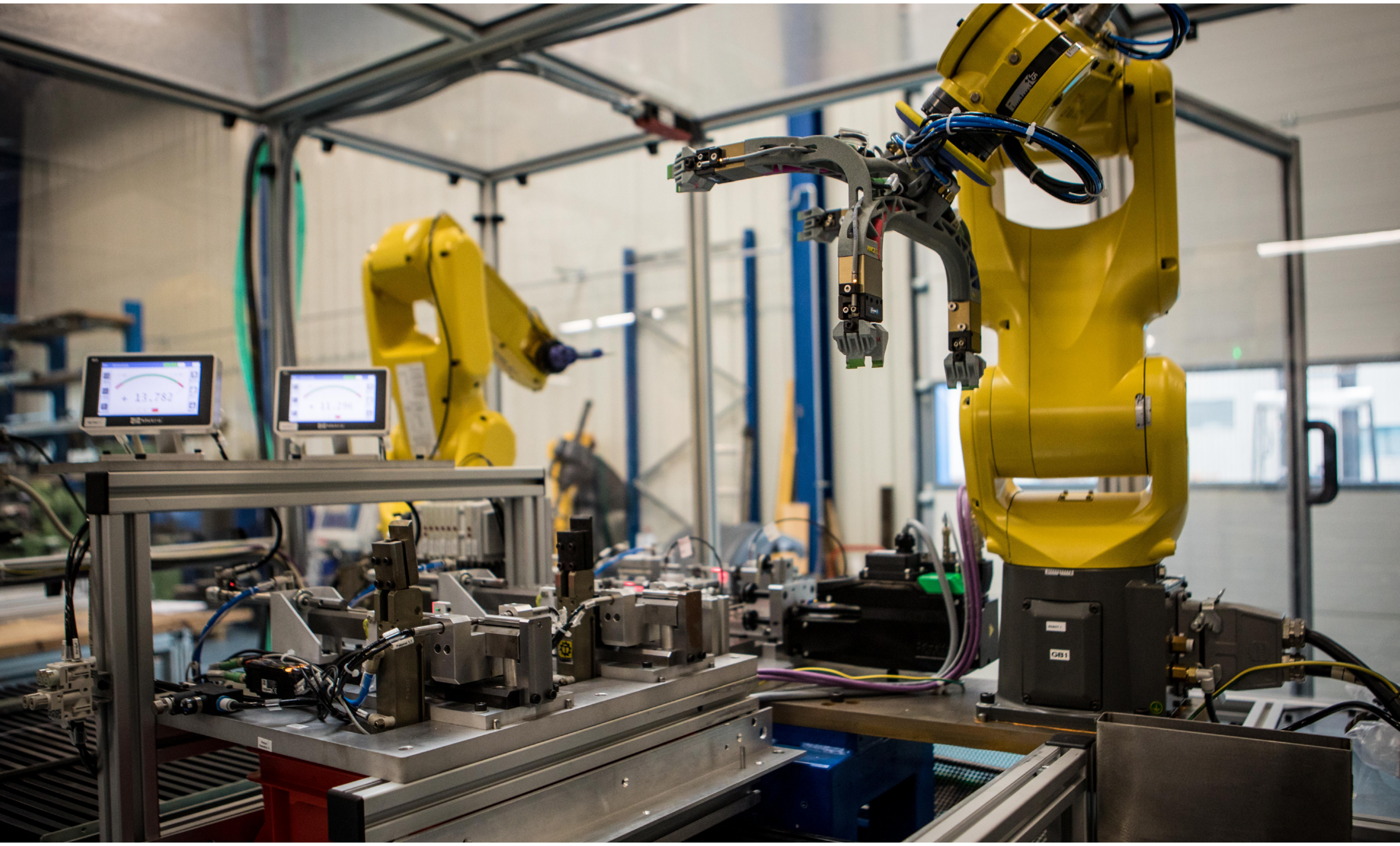
ROBOTICS BUSINESS REVIEW

WHITEPAPER



Additively Manufactured Robotic End-of-Arm Tooling:

Challenges, Solutions, & Opportunities

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Additive manufacturing and robotics automation, both synergistic and on an accelerated growth path, are revolutionizing the manufacturing sector. A growing number of opportunities exist for robotics-enabling technology OEMs and system integrators offering solutions that leverage the capabilities of the respective technologies for the benefit of the other. This is especially true for the use of 3D printing for the fabrication of robotics end-of-arm tooling.

The manufacturing sector is responsible for the majority of robotics systems deployments.

Advances in hardware and software technologies, ongoing academic research, and dramatic increases in robotics investment, have had the collective effect of enabling the development of practical, robust, commercial-class robotics products, technologies, and services in support of applications in a great number of industries. Manufacturing, in particular, has benefited from robotics automation, with the sector responsible for the bulk of robotics systems and applications.

Deployment of industrial robotics is strong (Figure 1) and this growth is expected to continue to be driven by new robotics solutions and enabling technologies such as collaborative robots, autonomous mobile robots (AMRs), AI / machine learning, 3D printing (3DP) and more.

The challenges facing manufacturers equates to new product and services opportunities.

Massive Opportunities

The opportunity landscape for robotics OEMs, enabling technology providers and systems integrators is wide open at this time, especially for those suppliers offering solutions for the manufacturing sector. As is always the case, the greatest opportunities map to overcoming those critical gating factors and challenges facing manufacturers, as well as exploiting the latest manufacturing innovations, including new technologies, products, services, and methodologies.

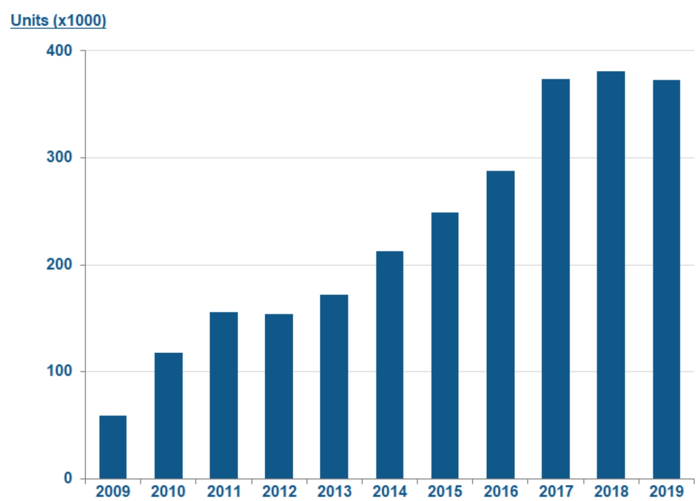


Figure 1. Annual deployment of industrial robots. (Credit: IFR World Robotics 2020)

NEW AND EVOLVING CHALLENGES

All manufacturers are under constant pressure to increase efficiency and improve the quality of produced goods, while reducing costs. Manufacturers also continue to face strong competition from producers across the globe. Speed-to-market for manufactured goods has never been more critical.

These traditional business drivers have now been joined by other mandates such as Environmental, Social, and Corporate Governance (ESG) initiatives to reduce material waste and energy use. In today's era of mass customization, manufacturers are also required to produce more variations of products, and this proliferation – known as SKU explosion – will only accelerate. Labor pool variability, as well as the growing skills gap for manufacturing work, also tests manufacturers.

Value drivers for robotic automation now includes efficiency, agility and flexibility.

These challenges, and other contributory factors, will necessarily increase the levels of robotic automation adoption among manufacturers. But unlike the earlier generations of robotics deployments, where the primary objectives were productivity and quality improvements, the value drivers for the next generation of robotic automation also includes extreme efficiency, agility and flexibility.


Credit: HP

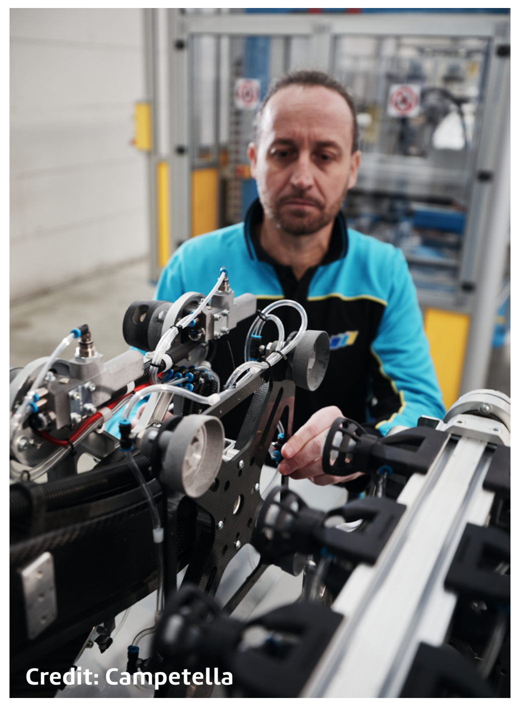
ADDRESSING CHALLENGES

A number of solutions have been developed and evolved over time that address the multitude of acute challenges today's manufacturers face. 3D printing service bureaus, contract manufacturers that specialize in AM/3DP and often offer design and engineering services, along with new business models for leasing robots (Robotics-as-a-Service or RaaS), are just two examples. Others include:

Collaborative robotics is the fastest growing industrial robotics sector.

- **Collaborative Robotics –** The introduction of collaborative robots, robotic systems that can work safely in close proximity to human co-workers, has increased task flexibility and expanded the number and types of applications for which robots can be used. Both large, existing robotics suppliers, as well as new, smaller firms, have rapidly introduced innovative collaborative robotics technologies into the market, and more are on their way. According to ABI Research, the market for collaborative robots will reach $600 million in 2021 and $8 billion by 2030, with a projected CAGR of 32.5%.

- **AI / Machine Learning –** Any Internet search using the terms "AI", "machine learning" (and its subset "deep learning") with the word "robotics" will return a slew of commercially available solutions for critical robotics functions including decision making, object identification, vision processing, autonomous navigation, motor control, sensor integration and more.



Credit: Campetella

For manufacturers, "flexibility is the new productivity".

- **Agile Production Methods –** Today, manufacturers are demanding robots and other technologies that support Agile Manufacturing, flexible production processes that make no assumptions as to volume levels or even types of products being manufactured. Agile methods are extremely well suited for 21st century manufacturers, who must be flexible and responsive to customers that demand rapidly produced, constantly changing, high-quality products manufactured at low cost. For these manufacturers "flexibility is the new productivity", where flexibility includes task flexibility, application flexibility, location flexibility, and more.

3DP is increasingly being employed for the production of final, finished goods.

- **Additive Manufacturing and 3DP** – Manufacturers are increasingly using additive manufacturing (AM), the industrial production name for 3D printing, and fundamentally transforming the way objects are made in the process. For example, a recent PricewaterhouseCoopers (PwC) study noted that approximately two-thirds of US manufacturers have adopted 3DP, with 51% using it for prototyping and final-products, compared to 35% two years earlier. Innovation and investment in the additive manufacturing sector is very strong at this time, resulting in rapidly expanding capabilities even as prices for 3DP solutions become more accessible by the day.

There are a number of different additive manufacturing technologies, including fused deposition modeling (FDM), Multi Jet Fusion (MJF), selective laser sintering (SLS), stereolithography (SLA) and more (Figure 2). Each technique has its own advantages and areas of applicability, but in all cases CAD data is used to fabricate three dimensional objects by depositing materials – liquids, powders, or others – layer by layer until the object is complete.

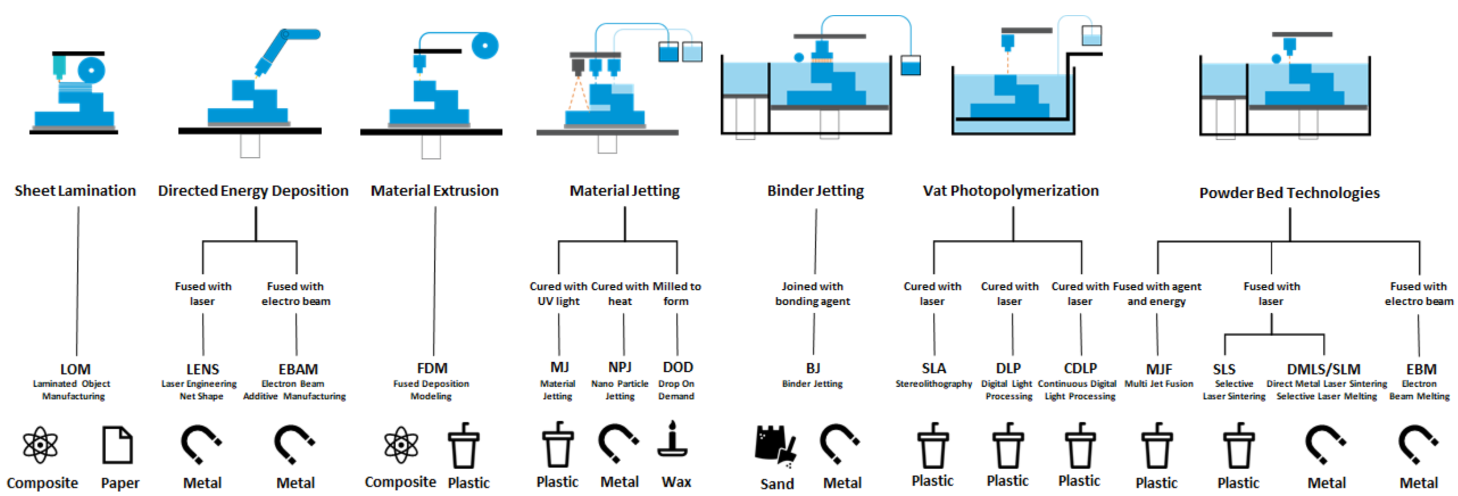


Figure 2: Additive Manufacturing Technologies. (Credit: HP)

3D printing will not replace traditional manufacturing, but it is increasingly being employed to complement established methods such as CNC machining, injection molding and casting. Yet there is a rapidly increasing list of applications where 3D printers are able to deliver accurate, often complex, designs quickly, with less material waste, and produced using an expanding inventory of printable materials.

"Data at scale" is the fuel which makes machine learning and advanced analytics possible.

- **Industrial IoT –** The Industrial Internet of Things (IIoT) includes all manner of physical devices, including motors, robots, controllers and more, embedded with both passive and active sensors and tags, allowing those objects to connect and communicate with other industrial devices, to collect and exchange data, and issue commands. The massive volumes of captured industrial automation process data are used for analytics and machine learning for performance enhancement and optimization.

- **Digitalization –** Many manufacturers are undergoing a fundamental transformation in the name of efficiency, flexibility and cost effectiveness, beginning with conversion of analogue practices into digital formats. Examples include 3D CAD files and "digital twins" which mirror the objects being manufactured.

  This 'Digitalization' of manufacturing also includes the confluence of IoT's pervasive sensing and connectivity, cloud computing, advanced data analytics, and AI / machine learning. The digitalization of manufacturing will be incremental, but also inexorable and transformative.

Credit: Gimatic

Cross Enabled and Cross Functional

There is a clear interdependency among the different solutions and approaches described above, with the sum being much greater than the individual parts. Taken together, these technologies and methods fall under the aegis of Industry 4.0, which is characterized by the bridging of the cyber and the physical, the digitalization of manufacturing for the factory of the future.

3DP / AM FOR ROBOTICS APPLICATIONS

Additive manufacturing technologies, especially 3D printing, are a constant focus for innovation. As a result, the cost of 3DP hardware continues to drop, as do processing times, while the precision and consistency of output continually improves. New, inexpensive, materials, are also developed and come to market, with the result that 3DP can take on an increasing number of manufacturing tasks, many of which were formally limited to traditional techniques.

Robotics and 3D printing are naturally synergistic.

One area of ongoing innovation involves the combination of robotics technologies and 3DP. Robotics systems share many features in common with 3D printing, and the two technologies are naturally synergistic. For example, both classes of technologies can be programmed to perform a task, and then reprogrammed to support a different function. 3D printing can be used to improve and expand the functionality of robotic systems.

3D Printing Enables Robotics

A wide range of 3D printing technologies are commonly used to support and enhance robotics automation. Many companies are employing 3DP solutions based on fused deposition modeling (FDM), the technology behind a huge number of desktop 3D printers, or stereolithography (SLA), a method of 3D printing that utilizes a laser and resin, as quick and cheap methods for rapid prototyping. Firms will also employ powder bed 3DP technologies such as selective laser sintering (SLS) and Multi Jet Fusion (MJF) that are known to result in more durable end use parts.

Manufacturers new to additive manufacturing typically begin using 3DP to quickly and inexpensively generate prototypes that can be used as a source of information and verification when developing robotics manufacturing applications. This is often followed by using 3DP to rapidly create custom jigs, molds, and fixtures necessary to position or hold objects. In both cases, objects are typically produced in low volumes making them especially suitable for 3DP techniques.

3D printing is also used to create the final parts for the robotics systems themselves. In many cases, the 3D printed components are superior to the same pieces produced by traditional methods, and as a result 3DP increasingly becomes the primary process for manufacturing robotics componentry. For example, Campetella Robotic Center, an Italian manufacturer


Credit: Campetella

of industrial robots and injection molding systems, uses HP's Multi Jet Fusion 3D printing technology to produce spindles for the company's labeling systems, reducing the weight of the spindles by 50% compared to the same part created using CNC machines.

Manufacturing of EOAT has emerged as a critical, high value application of 3D printing.

In addition to prototyping and manufacturing, one critical application that has emerged for 3D printing in support of robotics automation involves the manufacture of end-of-arm tools (EOAT) or end effectors, the generic names applied to those devices attached to the end of the robot's arm that allows the systems to interact with parts and materials. 3D printing technology provides a cost-effective, efficient, and often technically superior alternative to the traditional approaches for purchasing or manufacturing EOATs.

Credit: IAM 3D HUB

SOLUTIONS FOR ROBOTICS EOAT

The most common form of EOAT are mechanical grippers.

End-of-arm tools represent the business end of industrial robotics systems and are key to a robot's ability to carry out a task. They are also application-specific depending on the parts being handled and the actions the robot is required to perform. As you would expect, EOATs are the most variable of robotics enabling technologies. Examples include nonprehensile tools such as welding torches, routers, grinders and sanders, as well as prehensile grippers. The most common form of EOAT are mechanical grippers (Figure 3), of which there are many different types and sizes designed to grasp, hold, and position a wide variety of objects.

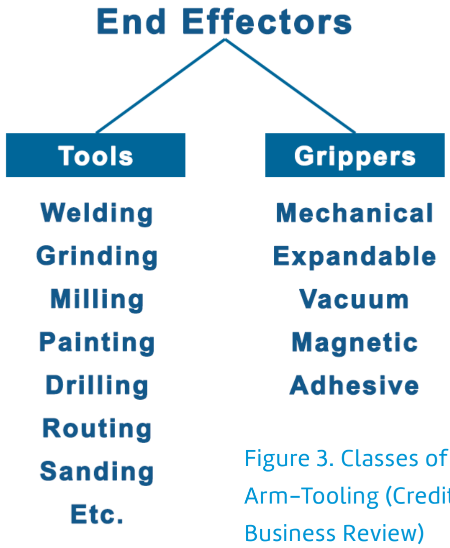


Figure 3. Classes of End-of-Arm-Tooling (Credit: Robotics Business Review)

Existing Solutions Suitable, But...

Until relatively recently, there were three primary sources for EOAT. The first, robotics companies and dedicated EOAT suppliers, typically sell high quality and functional products in volume. But the generalized tools from these suppliers are often quite expensive, and out of necessity only a limited number of form factors and materials are available.

Alternatively, companies or systems integrators can manufacture their own, bespoke EOAT solutions. CNC machining is the most common technique for manufacturing EOAT. Although CNC machining delivers application-specific tools, the process can be costly and time-consuming.

Traditional EOAT are often ill-suited for Low Volume / High Mix production runs.

For these reasons and more, EOAT that are purchased or manufactured using traditional techniques are often heavy, rigid, and inflexible, and typically employed for High Volume / Low Mix (HVLM) applications where EOAT changeover is relatively rare. In many cases, these EOAT solutions are less suited for Low Volume / High Mix (LVHM) 'agile' production runs that are increasingly in demand.

3D PRINTED EOAT

3D printing provides a very compelling alternative to traditional sources or methods for acquiring end-of-arm tooling. The benefits of using additive manufacturing for EOAT production include:

• Rapid Design and Production	• Lower Manufacturing Costs
• Reduced EOAT Weight	• Greater Design Freedom
• Lower Energy Costs	• Less Production Waste
• More Complex Parts	• Application Optimized Forms

Table 1: Benefits of 3DP for Gripper Manufacturing

The cost reduction from the 3D printing of EOAT is attributable to many sources.

Cost Savings

Modern 3D printing technologies and techniques allow for the production of customized EOAT solutions at a lower cost than either purchasing products available for sale or produced by traditional machining and manufacturing methods. The cost reduction comes from many sources including the reduction or elimination of machining steps and tooling costs, the use of lower cost materials, using less raw material, and more.

Credit: Gimatic

CNC Würfel, an automation specialist based in Singen, southern Germany benefited from the reduced cost of 3DP production when the company sought less expensive and faster fabrication methods for a type of gripper adapter they supply to their clients. By migrating to additive manufacturing methods for production of the adapters, the company was able to realize a savings of 66% while cutting production time by two months.

Rapid Production

Rapid production of robotic end effectors results in significant business benefits.

A key advantage of 3D printed end effectors is that they can be produced rapidly in any number of sizes and shapes depending on customer need. Consider, for example, Gimatic, a global manufacturer of pneumatic and electric grippers for industrial automation. Gimatic uses 3D printing to quickly generate functional gripping solutions for their customers, and to make gripper parts which can be delivered to their customers the day after the order was placed. Thanks to 3D printing, the company has also increased their portfolio of gripping products available to clients, and consequently expanded their business.

Reduced Weight

It is advantageous for robots to employ low weight EOAT.

Smaller robotics systems, including the new generation of collaborative robots, perform better with lighter grippers. With 3D printing, manufacturers can use less material than with traditional methods to create lighter and smaller tools that are still extremely strong. This has many advantages for articulated robot arms including reduced load on motors, faster acceleration/deceleration, and lower inertia.

Greater Design Freedom

Conventionally fabricated grippers are extremely complex, featuring a large number of assembled components.

3D printing can create EOAT and grippers with features and capabilities not found in gripping solutions produced using traditional methods. Using 3D printing, multi-part assemblies can be consolidated down into a single part, and can include integrated features such as vacuum channels. As such, creating intricate parts using 3DP methods does not incur the cost penalty for producing complex designs when employing traditional manufacturing techniques.

Grippers can also take on shapes that optimally conform to the object being manipulated. They can even be printed in color. Case in point… French engineering services firm Seb'Automatisme uses Multi Jet Fusion (MJF) 3D printing technology to create lightweight grippers for robotic

machine tending systems, along with other componentry, incorporating color logos, serial numbers and more. Based on the 3D printing technique used, the company can optimize for different degrees of strength, flexibility and other characteristics for each object.

The materials used for 3D printing of EOAT is based on what it best suited to the task.

Range of Materials

There is a large and increasing number of materials that can be used to manufacture EOAT, allowing for application-specific optimization. End effectors can be produced using materials ranging from the very rigid to soft and flexible, utilizing various classes of metals, thermoplastics, photopolymers, composites and more to achieve application-specific goals. For example, Forerunner 3D Printing, a 3D printing service bureau based in the US, utilizes thermoplastic polyurethane (TPU), an elastic polymer resistant to grease and oil, to produce custom, flexible gripper pads and suction cups for grippers and other EOATs that also exhibit high levels of abrasion resistance.

At the other end of the materials capabilities spectrum is nylon, which is tough, and exhibits strong tensile and impact strength. As such, nylon is frequently used for 3DP, often for fused deposition modeling (FDM) as a filament, and for Multi Jet Fusion (MJF) as a powder. For instance, IAM 3D Hub, a digital innovation center based in Spain specializing in additive manufacturing, uses MJF and nylon materials to produce grippers that are robust, yet 85% lighter than earlier classes of the tools produced by other means. It also takes 30% less time to generate the 3D printed grippers compared to traditional methods.

BENEFITS FOR MANUFACTURERS AND EOAT PROVIDERS

The manufacturing sector is rapidly increasing the level of robotic automation in response to the traditional mandates and challenges that drive robotics adoption, as well as in reaction to new business value drivers and social imperatives. Also fueling this trend is the availability of new classes of innovative, contributive solutions such as collaborative robots, AI and machine learning techniques, agile production methods, industrial IoT architectures, and the continued digitalization of manufacturing which undergirds it all.

3D printing is a robotics innovation driver.

3DP Supporting Robotics

Like these other robotics innovation drivers, 3D printing, too, is expanding the capabilities of industrial robots and accelerating robotics automation overall. 3DP has found great success as an exciting new method for the manufacture of robot parts and supporting fixtures. An increasing number of robotic system integrators and specialty EOAT manufacturers are using AM as their go-to manufacturing technology for producing EOAT.

3D printing of EOAT provides both technical and business advantages.

3DP and Robotics EOAT

3D printing has also had a very positive impact on robotics for the production of custom EOAT, especially robotics grippers. Using 3D printing techniques, robotics grippers, the most critical and variable component of industrial robotics systems, can be produced much more quickly, at lower cost, and with greater design freedom compared to traditional methods.

Strategic Value

Each of the tactical benefits derived from 3D printing deliver competitive advantages to the manufacturers employing additive manufacturing. But taken together, they also play a critical role for manufacturers as enablers for the strategic value drivers of agile manufacturing and digitalization (Table 2).

• Cost Reduction	• Enter New Markets	• Utilization Improvement
• Cost Avoidance	• Primary Revenue Increase	• Value Enhancement
• Cost Containment	• Incremental Revenue Increase	• Quality Improvement
• Efficiency Improvement	• Existing Market Share Increase	• ESG Observance
• Productivity Improvement	• New Products/Services Introduced	

Table 2: Strategic Value of 3DP for Manufacturers

GETTING STARTED / LEARNING MORE

Companies new to 3D printing for manufacturing and other industrial applications, would be well served by contacting leading suppliers of 3D printing solutions to learn how powder bed fusion technologies like MJF and SLS can be used to create EOAT parts.

There are many sources of information and guidance for both 3DP novices, as well as those experienced with the technology.

3D printing services bureaus, contract manufacturers that specialize in additive manufacturing, are also excellent sources for information and guidance. These companies typically have experience with a range of AM technologies, and also provide consulting services so that part designs can be optimized for their specific application. Services firms allow companies to experiment with 3DP designs without the necessity of up-front capital expenditures.

The same applies to those firms with 3DP experience that wish to have a deeper understanding of the very latest 3D printing products, technologies and methods, as well have access to use cases, detailed ROI analyses and other resources. In addition, 3D printer manufacturers and their reseller partners often have Applications Engineers and/or dedicated professional services teams within their organization that can bring their experience to bear for initiating trials and benchmarking studies.

Credit: HP