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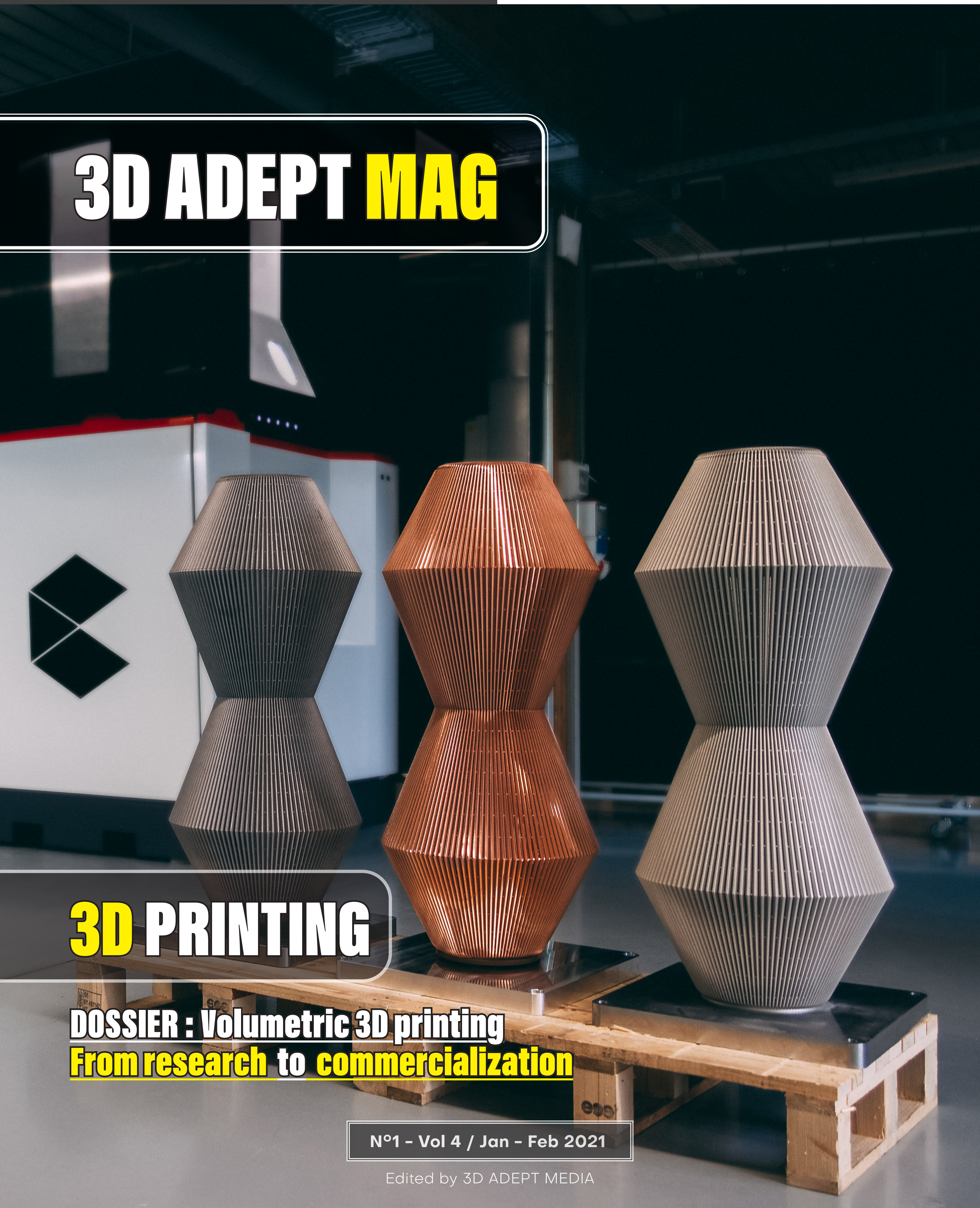

3D PRINTING

DOSSIER : Volumetric 3D printing
From research to commercialization

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SCAN ME

3D ADEPT MEDIA
All about Additive Manufacturing

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Hello & Welcome

It's about speed.

It's already been a month since we bid goodbye to 2020 and have welcomed with great hope the New Year.

Throughout the preparation of this first issue of the year, we came to realize that things were not necessarily new. In some aspects of life and in some places, it was as if things have not changed that much except the flip of a new calendar page but a closer look at the environment shows that we should not look at what's new in 2021, but the fast pace at which the situation evolves. Look at the speed at which Covid-19 vaccines have been brought to market, look at the speed at which people are getting vaccinated… In the manufacturing industry, the question of speed has never been as important as it is today. If you are a company that wants to create an efficient production line, then the questions of speed, cost, and quality will be of paramount importance. If you are a Space company that is taking its first steps into a new market – for instance, the satellites market–, here again, speed will play a crucial role.

In a nutshell, these few examples make us believe that the ability to act fast might be one key to stand out. Be it in the exclusive feature, the metal AM segment, the Interview of the month or the segment dedicated to AM users, this issue of 3D ADEPT Mag explores "speed" through various manufacturing perspectives.

After all, as the saying goes "there is no speed limits on the road to success".

Kety SINDZE
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Editorial


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Image : 3D printed figurine produced with xolo's volumetric 3D printing technology. – Credit: xolo

VOLUMETRIC 3D PRINTING : FROM RESEARCH TO COMMERCIALIZATION

There are so many additive manufacturing technologies which promise a lot and deliver little that sometimes, it's hard to perceive their effective role in manufacturing. However, a relatively new technology called volumetric 3D printing is increasingly gaining traction for good reason: not only does it intrigue by a process that is way different from the well-established layer-by-layer processes, but it promises a lot more: the ability to print an entire object in one go – and a few seconds. Wouldn't that be a dream come true?

To make it easier for us, we use the term "volumetric 3D printing". Note that this new technology has more than one fancy names: tomographic 3D printing, xolography (named this way by XOLO), volumetric additive manufacturing - for those who would like to point out the industrial perspective of the technology - or even "system and method for a three-dimensional optical switch display (OSD) device". This latter is an invention of Dallas-based Southern Methodist University that was granted a patent by the US Patent Office.

However, a company that commercializes a holography technology has often called volumetric printing "Hologram 2.0". **Volumetric prints however are not produced in the same manner as holograms,** in that there is no interference pattern generated or used in basic volumetric prints.

Anyway, it's already been five years that volumetric 3D printing has been in the research stages but the process receives even more credibility last year when some experts in the field announced the commercialization of their technology.

First, let's find out what volumetric 3D printing is

Volumetric 3D Printing (V3DP) is quite complex to define. In this process, a pattern is projected into a vat of transparent photopolymer liquid repeatedly from all angles. This resin-based technology is often compared to SLA printing. However, what makes it outstanding is the fact that rather than curing the resin by projecting a 2D image of the current layer into the container, V3DP uses several lasers to create intersecting points within the liquid. Moreover, whereas resin-based 3D printers cannot withstand oxygen, the latter can be used as an additive in V3DP as the operator must slow down the solidification, as the light patterns must pass through resin freely for some distance.

Among the scientists that have reflected on the topic, three groups are quite interesting to follow:

1 – **Brett E. Kelly, Indrasen Bhattacharya, Hossein Heidari, Maxim Shusteff, Christopher M. Spadaccini, Hayden K. Taylor**, researchers from the University of Berkeley reported on the technology they developed via tomographic reconstruction. Their report reads:

"We developed a method, computed axial lithography (CAL), that allowed us to synthesize arbitrary geometries volumetrically through photopolymerization. The CAL approach has several advantages over conventional layer-based printing methods. Our method may be used to circumvent support structures, as it can print into high-viscosity fluids or even solids. Printing 3D structures around preexisting solid components is also possible with our approach. CAL is scalable to larger print volumes and is several orders of magnitude faster, under a wider range of conditions, than layer-by-layer methods".

2 – Researchers from the Ecole Polytechnique Fédérale de Lausanne and founders of Readily3D, **Damien Loterie, Paul Delrot**, and **Christophe Moser**.

"During our Ph.D. studies, we discussed on multiple occasions new concepts for photopolymerization that involved shaping light beams in 3D to create the desired object. Our project really took off when, in 2017, we decided to test experimentally whether we could make a 3D object by illuminating a photosensitive resin from multiple angles, which was the basis for tomographic printing. These initial experiments were surprisingly successful, and we realized that we were onto something".

Readily3D's technique is also based on the principles of tomography. Their process works by sending a laser through a translucent gel – either a biological gel or liquid plastic.

3 – And **xolo**. Founded in January 2019, the majority of the team worked on xolography throughout 2019. The team explained: :

"The xolography technology can very well be described as a process in which a planar printing zone is continuously – and with high speed – moving through a photopolymer tank rather than photopolymer slowly moving from a tank into the print zone – [as seen in a] conventional SLA/DLP printer."

Despite the uniqueness of each of these volumetric 3D printing approaches, we might be tempted to think that this approach is no longer 3D printing as it does not meet the layer-by-layer principle. The truth is, although we do not see the well-known "Z-axis" operate, in these approaches, the process works simultaneously in three dimensions at the same time.

"Most 3D printing technologies rely on an additive layer-by-layer process. Volumetric printing, however, relies on a photopolymer-filled vat in which each voxel (3D analogue of a pixel) can be selectively addressed to convert it from the liquid (uncured) state to the desired hard (cured) material state", xolo explains.

Furthermore, at the level of materials, the viscous resin can allow for the integration of much more additives than common resin-based 3D printers could contain, which opens up more opportunities for the development of new materials.

In this vein, the process which is quite similar to SLA/DLP 3D printing (– and where there are no layers –) can be seen **as a new generation of additive manufacturing technologies as parts solidify instantly in three dimensions.**

Addressing one urgent issue in manufacturing

The most significant advantage of V3DP is speed. So far, AM technologies deliver an entire part in a few days or hours depending on the technology used. V3DP promises the fastest printing speed we have ever seen in the AM industry as it can print an entire object in seconds or minutes.

"The most spectacular aspect of our technology is speed: because the whole volume is solidified at the same time and not layer-by-layer, objects can be printed in just a few tens of seconds. This is revolutionizing as it is unmatched by any other method at similar scale and resolution", the team at Readily3D said.

Xolo could not agree more with Readily3D: the V3DP technology is the basis for unprecedented speed and design freedom *"as printed parts do not need to be attached to a platform anymore."*

And there are other advantages as well:

"Printing directly within the resin volume also solves additional challenges of traditional AM systems. For example, ***we do not require temporary supports*** *to print hollow structures or overhangs, because the object is held in place by the resin during the relatively short print time.* ***The lack of mechanical contact between printer and resin*** *also means that we can print within sealed, sterile containers. Finally, we are able* ***to print soft and deformable materials****, which tend to be challenging or impossible to make on AM systems based on deposition or recoating operations".*

"Volumetric 3D printing will challenge the state-of-the-art only where customers are unhappy with existing solutions. Think of time-sensitive applications or manual removal of support structures, the staircase effect, etc. With the release of the xube, we hope to inspire creative minds for applications that were not realizable before. We want to enable products that were unimaginable before", the team at xolo explained to us.

Volumetric 3D printing technologies and their specifications

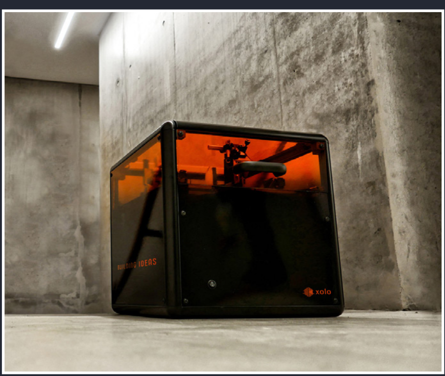
The buzz around V3DP might be hard to ignore but reality shows that the list of companies that are moving from lab to markets is still very short.

In the research field, in addition to the aforementioned researchers from Berkeley University, a group of researchers of the University of Michigan tackled the issue. Still in the research arena, Siemens Energy filed a patent for "*Systems And Methods Of Volumetric 3d Printing*" in 2018 that describes a process similar to the one developed by **T3DP**, a California-based startup developing 3D printing technology. The latter relies on a resin comprising an "optical molecular switch molecule, wherein the optical molecular switch molecule has a non-fluorescent state and a fluorescent state, wherein at one wavelength of optical excitation the molecule has a first state, and at a second state the optical molecular switch molecule fluoresces at a second wavelength of excitation."

Also, for reasons that are currently unknown, we have discovered that Disney also holds a patent for "near instantaneous object printing using a photo-curing liquid". Apparently, this would be a form of volumetric 3D printing.

For now, companies that are making V3DP a reality in the field by commercializing their technology are xolo and Readily3D.

The xube volumetric 3D Printer



German startup Xolo unveiled its new 3D printer at the end of 2020. Called xube, the system is based on a technology Xolo called Xolography (obviously!). The xube 3D printer is capable of fabricating small parts in about 20 seconds and large parts in 5 minutes.

"The xube is specially designed for curious researchers: While standard protocols are available for printing acrylics, it is open to individualization, all printing parameters can be chosen freely and any self-made material can be employed. The customer loads the printer with a photopolymer vat with dimensions spanning from >50 mm to 10 mm along with the space coordinates. Within seconds to about a few minutes (depending on the print size), the object is solidified with high accuracy based on a standard STL input file", xolo told 3D ADEPT Media.

According to the company, once the printed part – or the "solidified object" as per the words of xolo – is removed from the vat, "residual resin is washed off and depending on the material used, final material properties can be attained by photo/thermal processing".

xolo is currently making its technology available to research organizations.

The Readily3D's Tomolite printer

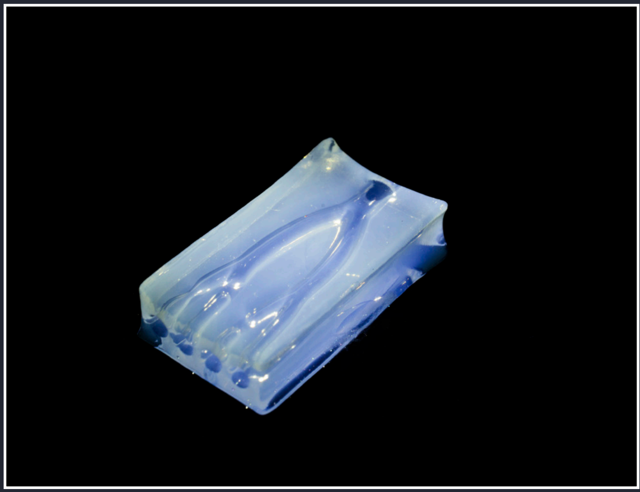
Readily3D's flagship product is named **Tomolite.** With a compact unit of 30cm x 40cm x 60cm and a build volume of 10mm in diameter and 27.5mm in height, the CE marked printer can find its place on any or laboratory bench.

Described as ultra-fast and user-friendly by its inventors, the unit cant print "centimetre scale object, out of soft and hard materials, in a few tens of seconds with 40 um optical resolution."

Unlike the xube 3D printer that may require an additional photo/thermal processing stage, Readily3D claims that no post-processing is required beyond washing.

Speaking of the printing process, the company explains: "the resin is first poured into a cylindrical vial, which is then hand loaded in the printer. The STL file of the object to print is generated by a CAD program. The printer comes with the Apparite software, which allows for the loading and handling of STL files, as well as the configuration of dose settings and printing monitoring."

To point out an application, the founders add: "our printer can shape light-sensitive bioresins into complex living constructs featuring vasculatures, pores and cavities that cannot be done with any other printers on the market with the same speed and resolution."



Legend : Block, natural, black background – Image via Readily3D

The 3D printer can be purchased by companies and public institutions. As a matter of fact, some units are already installed in several research centres in Europe.

Main applications of volumetric 3D printing

Our exchange with experts reveals that main applications of volumetric 3D printing can be found in optics, dentistry, audiology, bioengineering, microfluidics and prototyping. In a nutshell, sectors of activity that will require rapid and scalable methods to create centimetre-scale cell laden 3D constructs.

Currently, Readily3D believes that the market is already ready for dentistry and audiology applications as these sectors increasingly decentralize manufacturing by customizing directly the products in shops or in the practitioner's office.

Although it is still at its infancy, the promise of volumetric 3D printing is obvious. The commercialization and possible applications shared by Readily3D and xolo show that the technology is ready to be put in action.

Image: Xolo – Dental model

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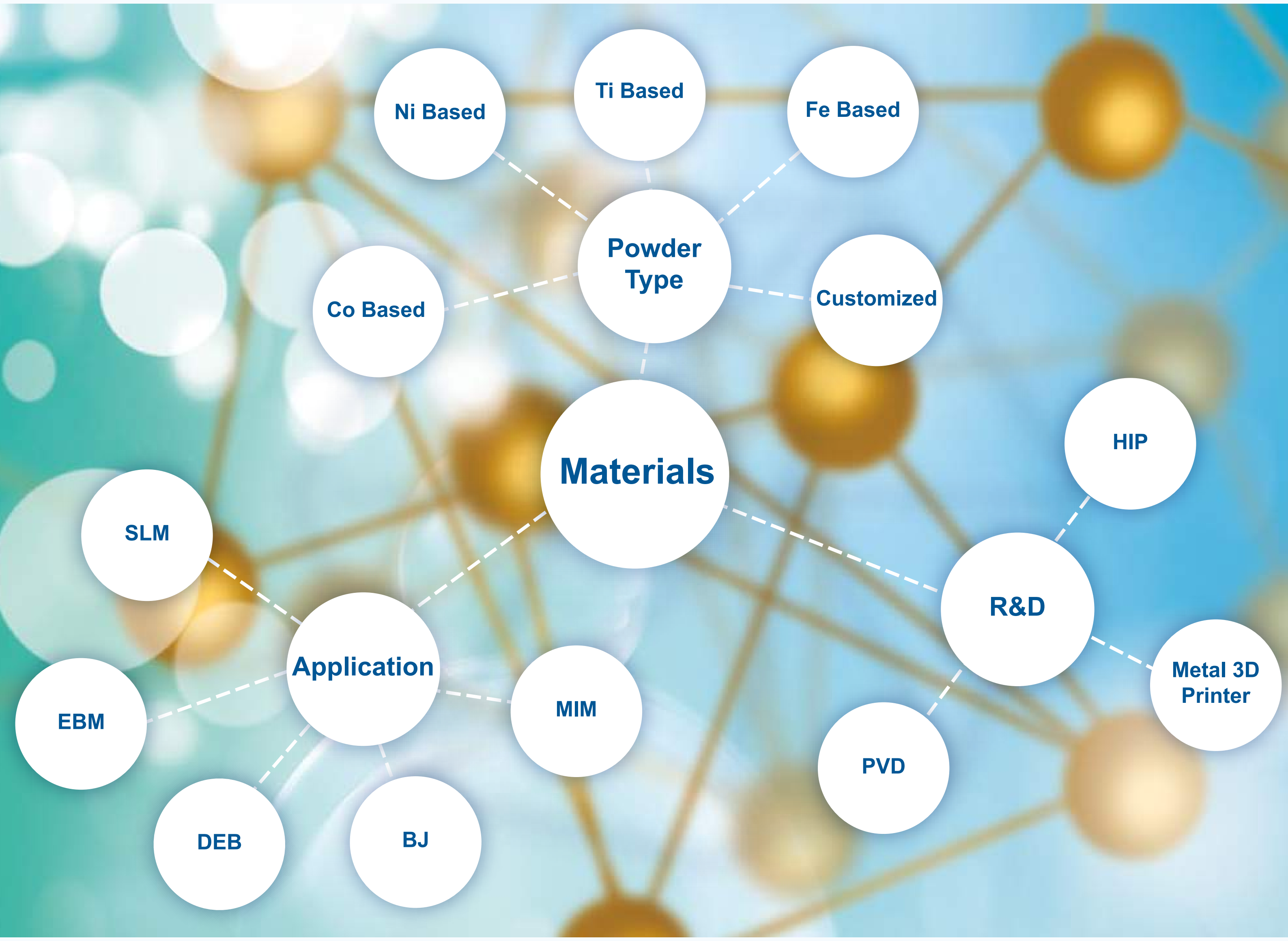

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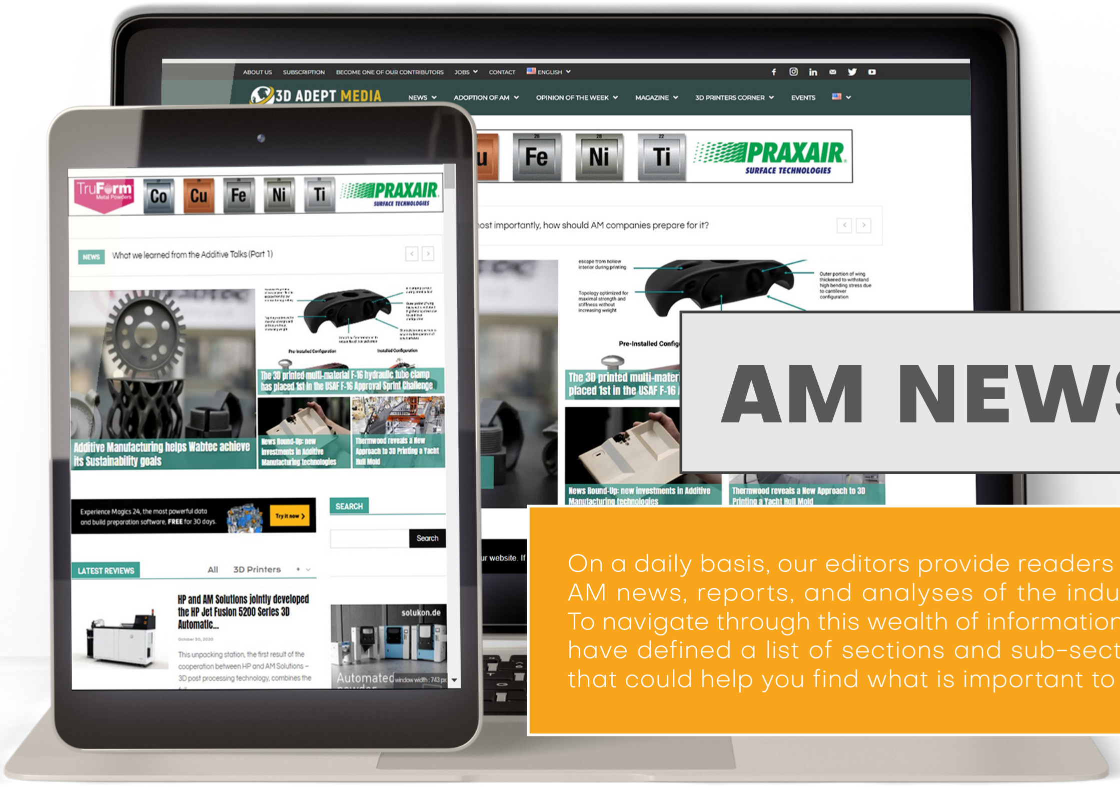

AM NEWS

On a daily basis, our editors provide readers with AM news, reports, and analyses of the industry. To navigate through this wealth of information, we have defined a list of sections and sub-sections that could help you find what is important to you.

Do you have any current information related to 3D printing or a press release that needs to be published ?

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WHAT DOES "SUPERSONIC" ADDITIVE MANUFACTURING LOOK LIKE?

In a production environment where increasing ROI is often the ultimate goal, manufacturers are always looking for ways to speed up the production of their products. But doing so comes with some risks. In the end, there is always a chance that changes in production could affect the quality of the end-product. How can you speed up your production process without jeopardizing quality ?

Companies that want to create an efficient production line know that questions of speed, cost, and quality will always be discussed. The more competitive the global market becomes, the more cost reductions and production speed become the number one solution to increase profit. To adapt to this new reality, companies opt for modern manufacturing processes such as AM. In general, many seem to agree with the design flexibility and material efficiency AM provides but despite those undeniable benefits, one thing AM technologies manufacturers struggle to significantly improve in their process is **speed**. We came to realize that there is one manufacturing technique that is particularly acknowledged for its ability to meet production speed requirements for certain industries: **Supersonic Particle Deposition** (SPD also known as Cold-Spray).

This exclusive feature aims to discuss the methods, challenges, and applications of this process and the reasons why it is uniquely positioned to meet the requirements of certain industries. To discuss these topics, we have invited two companies that have made this technique their core business: **Titomic** and SPEE3D. **Jeff Lang,** Founder of Titomic Limited, Executive Director and CTO as well as SPEE3D co-founders **Byron Kennedy** and **Steven Camilleri** are the main contributors of this exclusive feature.

Manufacturing at double speed

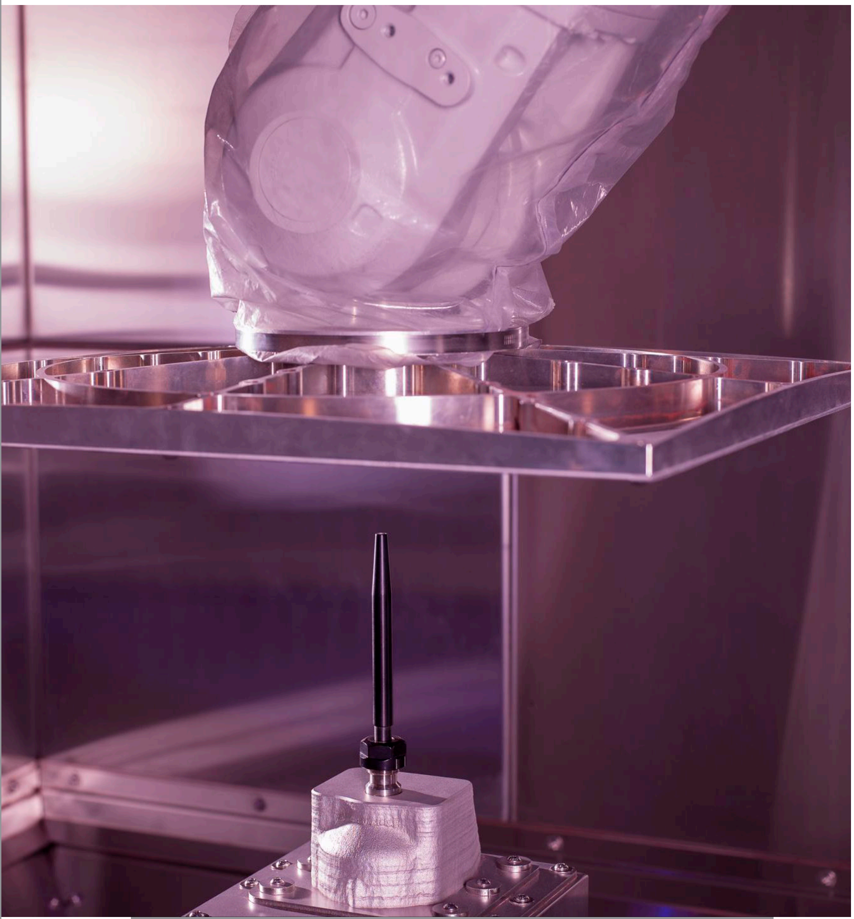
From an economic point of view, the ideal speed of manufacturing needs the perfect balance between the physical processes of production, the wider system that allows these processes to operate, and the co-ordination of a supply chain in the pursuit of meeting customer needs.

However, in manufacturing – and in additive manufacturing processes especially, things are slightly different. Speed starts raising challenges when manufacturers have to deal with **short lead-times** and when the goal is **large-scale production**. From this manufacturing perspective, operators who work on metal AM will tend to look for a process that opens up more possibilities in terms of materials and that would withstand very high melting temperatures to go very fast.

The only thing is, as per the words of **Jeff Lang,** *"the main factor, the metal 3D printing industry has struggled to realise, is its viability against the speed of traditional metal fabrication for industrial-scale metal parts, especially in the aerospace and defence industries."*

Indeed, *"in traditional AM, the metal powder is melted with a laser - that process takes a solid powder, melts it into a liquid, and then reforms that into a solid. That process takes time, based on physics, and is easy to calculate. In order to speed this process up for more efficiency, you needed a process that does not melt the powder"*, explain **Byron Kennedy** and **Steven Camilleri**.

Those challenges, therefore, lead to the increasing interest in supersonic particle deposition (SPD) additive manufacturing (AM) technology (also known as Cold-Spray).


Legend: WarpSPEE3D nozzle

So, what is Cold Spray?

As Titomic's Jeff Lang notes, Supersonic Particle Deposition (Cold-Spray) has been in commercial use for over 30 years but its application in additive manufacturing is quite recent.

Cold Spray is defined as a materials consolidation process whereby micron-sized particles of a metal, ceramic, and/or polymer are accelerated through a spray gun with a ***De Laval rocket nozzle*** using a heated high-pressure gas (i.e. helium or nitrogen). In this process, particles are said to exit at supersonic velocities and consolidate upon impacting a suitable surface to form a coating or a near-net shaped part using ballistic impingement.

The key innovation in this process would be the use of a "***de Laval nozzle***", a convergent-divergent nozzle that enables the metal powder to reach supersonic speeds. According to experts, the process has gained traction in additive manufacturing due to **its ability to apply multi-component coatings.**

Furthermore, unlike other powder deposition technologies, four main benefits characterize SPD: **no heat-affected zone, no interface oxides, generation of surface compressive stresses as well as no thickness limitations.**

This means that bonding between materials and particles does not usually require a thermal source. There is no melting and cooling cycle as the process is a solid-state one.

Materials Considerations & Post-processing

Since there is no heat, operators can easily explore the use of reactive materials such as titanium, aluminium, and magnesium.

According to SPEE3D's founders, *"every powder has what is called a deposition speed. When accelerating a power if its speed is too slow, the powder bounces off, too fast, and the powder will erode the substrate. In between is what we call the "speed deposition window"*. For example, copper can be deposited at 450 metres per second, aluminium at 600 metres per second, and stainless steel at 700 metres per second. These are the ideal speeds."

As far as SPEE3D is concerned, the founders explain that they accelerate *"the power to in-between Mach 1.5 and Mach 2 depending on the material we use (supersonic speed is greater than Mach 1 or greater than 343 metres per second)."*

However, attention should be devoted to the ductility of the sprayed material. Indeed, less ductile powders are less subject to deformation. In this case, the 3D printed part reveals a brittleness that one does not see in thermally processed parts. Interestingly, thermal post-processing such as Hot Isostatic Pressing (HIP) can remove these effects. On the other hand, more ductile materials (e.g.: aluminium, copper) do not present this characteristic, therefore require less post-processing.

Legend: Copper Hammer produced by SPEE3D

Different roads lead to "speed"

Amid this array of characteristics, the most impressing feature of cold spray remains **speed**. Needless to say, that to develop their technology, each manufacturer has brought something unique to their process.

Branded as **Titomic Kinetic Fusion (TKFTM)**, Titomic's patented process allows for the production of industrial-scale additive manufacturing of Titanium parts.

Lang recalls that in 2008, he was approached by the CSIRO, Australia's national science organisation, to look at creating a holistic value chain around Titanium of which Australia has the largest mineral reserves of this resource in the world.

"To unlock this value chain required a deep investigation into production technologies for Titanium fabrication with the intent to find the most viable process with the most unique value proposition. After investigating various AM technologies for producing Titanium parts, the one apparent thing was the limitations of build speed and size with melt-based AM processes. As I was looking to utilise large quantities of Titanium powder, I needed to find a suitable AM technology that was commercially viable against traditional Titanium fabrication methods", **Lang** explains.

Lang realized that due to its high- deposition rates, the high-performance metal coating process was a great bet to produce AM parts faster and *"without the size constraints of melt-based 3D printers."*

Today, the metal 3D printer manufacturer commercializes the **TKF1000 system** that delivers build speeds between 6-10 kg per hour depending on the type of metallic material used and its density.

Jeff Lang

"Our custom TKF systems can be configured with multiple heads to deliver build speeds of up to 75 kg per hour. As with all additive manufacturing equipment suppliers, there are some bold claims as far as build speeds that are unrealistic even though the machine may be rated to that maximum. On a single TKF system head, we can build 30-45 kg per hour, however there would be considerable porosity at these build speeds which affects the mechanical properties", the expert adds.

In the case of SPEE3D, it's a different route that led to the development of their cold spray AM technology.

With a decade of experience in manufacturing, SPEE3D is not **Kennedy** and **Camilleri's** first entrepreneurial journey. In the life they had prior to SPEE3D, they realized the potential of metal 3D printing but also deplored its limitations.

Image: Titomic

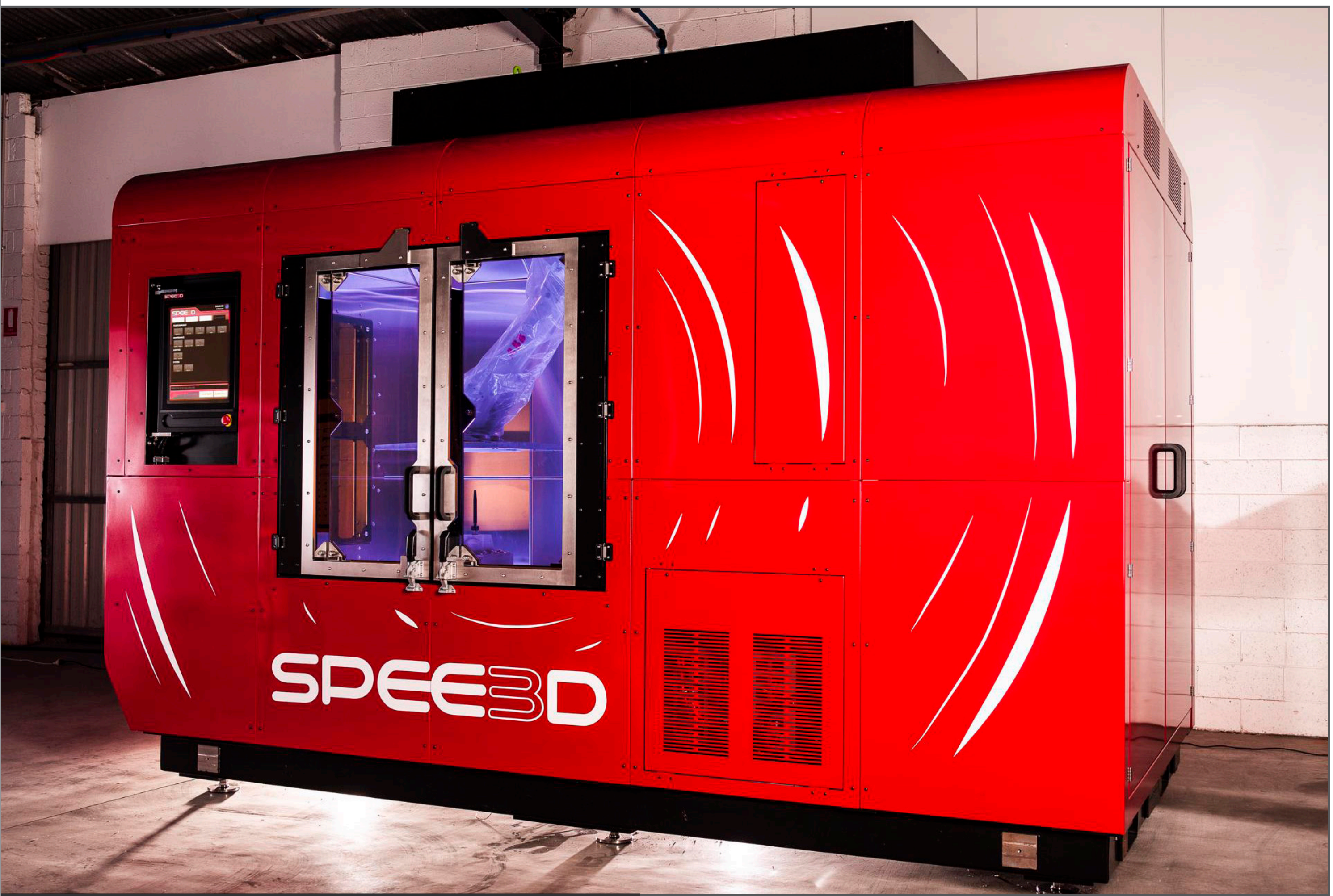
"The challenge, however, was that traditional metal AM was too expensive and too slow. So, when finishing up with the manufacturing company, we decided to enter the additive manufacturing space.

We began to look for a manufacturing-friendly AM technology – a fast and low cost technology. That is when we came across Cold Spray, which at the time was primarily used in military repair applications, and in a "manual way". We found that this was something that could be fixed. So, with a background in Control Systems and Robotics, we took a manual Cold Spray Process and turned that into a metal AM machine" the founders point out.

Both founders share their long-term goals : "the limitation in SPEE3D's printers is not the deposition speed, but the robotics keeping up with the Spray (Cold Spray). Theoretically, the process could be a lot faster, making the AM process even easier, and this what SPEE3D continuously works on as its long-term goal."

A close look at those two metal 3D printing processes shows that both technologies enable easy optimization of the build speed to achieve the desired geometries and mechanical properties – not to mention that post-processing (heat treating and/or post-machining) very much depends on the initial choice of material.

Co-founders Byron Kennedy (CEO) and Steven Camilleri (CTO)



WarpSPEE3D

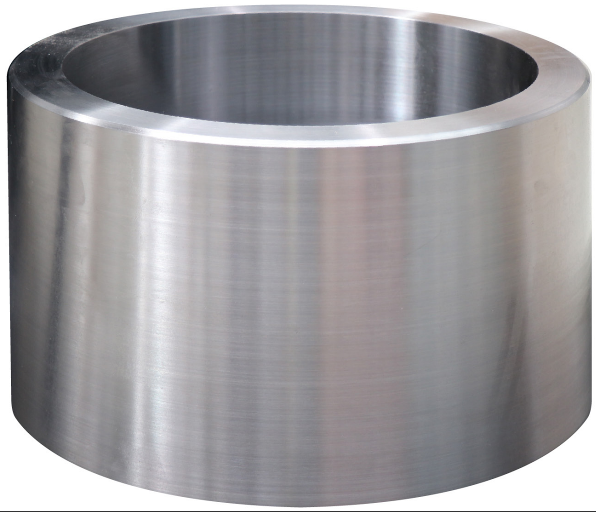
Applications & challenges

As it was first acknowledged as a metallic repair technology, first applications of SPD were seen in the repair of **magnesium helicopter gearboxes**. Manufacturers highlight the technology capabilities to manufacture parts such as **tools, brackets, pumps,** and as well as in **specialty components**. According to researchers, this primary focus on military applications is due to the need for frequent repairs on the battlefield.

Speaking of helicopter gearboxes, **Danielle Cote**, assistant professor of materials science and engineering and director of WPI's Center for Materials Processing Data notes: *"If you need to replace a part like that, it can take months or even years, and the cost is significant—assuming that the part is available or even still being made. To repair a gearbox with cold spray, you need alloys with high strength, toughness, and ductility. Our methodology will enable us to develop powders that can be used to effectively repair or even manufacture parts like that and get helicopters back in the air quickly. The Army is especially interested in portable cold spray systems, but the technology can also be used on a larger scale—in industry, for example—and it will be exciting to see how robots can help expand the use of this and other additive manufacturing processes."*

Apart from military and defence applications, we have also seen Cold Spray AM applications in the space industry and certain luxurious consumer products.

Nevertheless, Cold Spray AM seems to have great promise for mid-size companies. We cannot deny the technology readiness to meet certain industries' demands but its ability to meet large-scale production requirements remains to be demonstrated.



Legend: High Tensile steel part produced by TKF
Material: 4340 High Tensile Steel
Industry: Defence
Size: 450mm-D x 400mm-H x 50mm-WT
Weight: 131Kg
Titomic's TKF9000 can produce metal parts up to 9m in length, 3m in width and 1.5m in height.

Furthermore, researchers strongly encourage manufacturers to have a close look at materials selection as well as the microstructure and mechanical properties of deposits that may depend on different process parameters. In this vein, geometric control can often be a quite disturbing issue. *"Low geometric control is attributed to a range of key issues that limit the application of additive manufacturing technologies such as the necessity of post-machining, difficulty in fabricating complex shapes, geometry-induced property variations, and inconsistent quality of fabricated parts. Therefore, addressing the challenge of geometric control is undoubtedly of great importance in Cold Spray AM as well as other high-speed additive manufacturing technologies"*, the study reads.

Legend: Invar 36 Tool produced by TKF / Industry: Aerospace
Size: 800mm-L x 500mm-W x 450mm-H / Weight: 83Kg
The aerospace tooling industry has long been plagued with high costs and long lead times, this is typically associated to laborious manufacturing processes and high material wastage.
Near-net shape manufacture of tool face plates reduces the need to weld parts together, reduces machining time and overall cost. The TKF process also allows tools to be repaired and re-purposed by adding more material on existing tools to create new forming face geometries.

Concluding notes

Cold spray AM has opened up a new niche within the additive manufacturing industry due to its ability to manufacture near-net-shape parts in a variety of metals. The military industry is one of the primary fields that sees potential in the technology. Nevertheless, the adoption of the technology might be extended to sectors of activity that are looking to significantly reduce machining time and material waste and to produce parts in remote locations.

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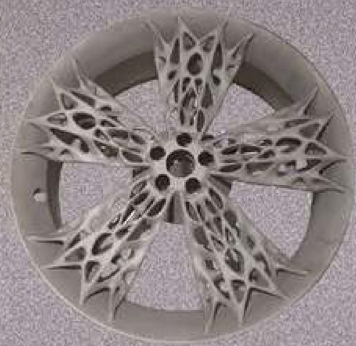

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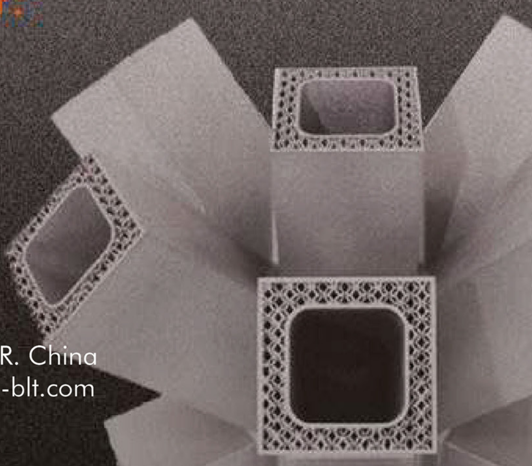

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THERE IS A MARKET FOR VERY LARGE 3D PRINTED PARTS

There are two types of additive manufacturing companies: those that are building their expertise and experience from scratch and those that rely on a much stronger expertise. Companies from the second group often bring a certain cachet that inevitably makes them credible for the challenge they are addressing.

We came to realize that in the field of *"Large Format Additive Manufacturing"*, **Thermwood** meets this unique criteria and an exchange with **Dennis Palmer, Vice President of Sales**, confirms why.

ITS STRONG BACKGROUND

In the additive manufacturing industry, Thermwood is known as one of the three companies providing very large format 3D printing hardware and services with composite chopped Fiber Reinforced Polymer (FPR) pellet materials and a quick throwback to the 1970s shows that it is far from being insignificant.

Thermwood's initial business consisted in extruding plastic parts. *"Due to various reasons, the product changed and new markets required three dimensional thermoformed parts to be trimmed. There was nothing on the market to meet our needs for this application, therefore Thermwood designed and built the very first CNC router. We make our own machine control system, and also developed 3rd generation cabinet design software for the woodworking industry"*, Palmer outlines.

Over the past 50 years, the US-based machine manufacturer did not only gain knowledge, it has also uniquely positioned itself as a company capable of addressing the requirements of this specific area of manufacturing.

With headquarters in the town of Dale, Indiana, an area known as the 'Wood Capital of the World' for the many woodworking companies and furniture companies operating there, one quickly understands the products portfolio delivered to the woodworking industry.
However, the focus on large scale AM of composites in the AM industry makes more sense when one knows that CNC routers (three-axis machines and five-axis machines) are mainly utilized in the aerospace, marine, automotive, plastics and military/defense industries; in other terms, industries that are upgrading their manufacturing portfolio with new technologies. Not to mention that, at the technological level, Thermwood's Large Scale Additive Manufacturing | LSAM (pronounced L-Sam for Large Scale Additive Manufacturing) is a hybrid technology that requires the capabilities of 3D Printing and CNC routers to deliver the desired part.
Anyway, today we have discovered a company that supplies machines, parts and service to various branches of the U.S. government as well as to U.S. defense contractors. As per the words of Palmer, 2020 saw a busy team supplying ***"machines to companies that were manufacturing COVID PPE products, as well as to industries [that provide items in need to those that elected to remain]home and not spend their money on vacations"***; industries that provided items such as motor homes, marine products and off-road vehicles. Furthermore, as AM received positive media hype in 2020, this also helped the company maintain ***"a large backlog of orders for [its] Large Scaled Additive Manufacturing (LSAM) systems."***

LSAM_1040

EXISTING & EMERGING APPLICATIONS

Although it was first seen as a process for concept modelling and rapid prototyping, AM in general has rapidly expanded to include applications in many sectors of activity. Despite their potential, it should be noted that all additive manufacturing technologies do not advance at the same pace.

As far as "Large Scale Additive Manufacturing" process is concerned, our expert states that it is still an emerging market.

"The machine has proven its worth in our current target markets, but only time will tell what future market sectors will be able to utilize the near net shape printing capabilities", the Vice President of Sales confirms. Current markets that already adopt LSAM include aerospace, automotive, marine and foundry. As a matter of fact, multiple machines from Thermwood are currently installed in several facilities across these industries.

Among the numerous applications that have been achieved using Thermwood's LSAM, the largest part to date the machine has ever 3D printed was a display. The enterprise's representative explains that it ***"was designed utilizing 225 printed blocks that were assembled to create a 93' tall structure with the base being approximately 30' in diameter." (That translates into a 28m structure with 9m in diameter).***

Moreover, among the numerous applications that have been made public, marine applications have increasingly raised a key interest within the manufacturing field.

Example of marine applications achieved with Thermwood's LSAM

Whether it is due to the surge of sales during the pandemic or not, companies are increasingly looking to improve the performance of boats. If carbon fiber continues to raise interest, the manufacturing stage sees more and more a focus on recycling and the combination of fiber composites and 3D printing.

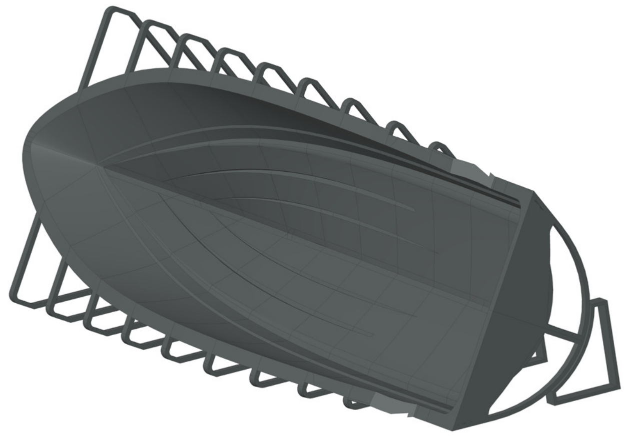
The latest example shared by the Indiana-based manufacturer **highlights a new approach to 3D printing a yacht hull mold**.

With the goal of demonstrating how only a single mold may be needed for the manufacture of larger vessels, Thermwood has 3D printed various sections from a 51-foot (15m) long yacht. For the manufacturing of a 10 foot section from the 51 foot long yacht hull mold (which means a 304 cm section from 1554 cm long yacht hull mold), a mold design was specifically developed with DfAM requirements in mind.

What's fascinating is that during the design phase, each mold section was associated a molded in rocker.

The section has required the 3D printing of various parts, each about five foot tall (152 cm) before being assembled using high strength polymer cables.

The company explained that when the mold is fully assembled, it rests on the floor on these rockers. At this point, the mold can be rolled over to tilt about 45 degrees to either side, kind of like a giant rocking chair. This allows for easier access during the layup process. A set of molded wedges are clamped to the rockers to hold the mold in the desired position. Once the hull has been laid up and fully cured, the mold is rolled to level and the printed wedges are clamped to both sides, holding them level. Then the two mold sides can be un-bolted and slid apart to release the finished boat hull.



Scott and the Yacht piece

Fabricated and trimmed on the company's 10×10 foot LSAM MT – the smallest machine from the manufacturer – the team used carbon fiber reinforced ABS as material because it is quite affordable compared to other reinforced thermoplastics.

This successful demo application may show the capabilities of Thermwood's LSAM but what makes it more interesting is that it truly works in practice – and this, beyond the boatbuilding.

As Palmer points out, "the LSAM can process parts from virtually any thermoplastic composite material used, including high temperature materials that are ideal for molds and tooling that must operate at elevated temperatures. LSAM's unique printing capabilities produces parts that are fully fused, vacuum tight and virtually void free".

Existing and long-term challenges to address

It is often said that AM of composite materials poses three main challenges: the problem of the homogeneous distribution of reinforcement material in the matrix, the availability of the raw material in a proper form and its imperfections while looking at the chemical variations of the feedstock materials as well as the selection of the ideal process parameters to manufacture these composite materials.

One cannot legitimately attribute these challenges to all manufacturers who specialise in the field, even less when these manufacturers develop hybrid and large-format AM technologies – bringing therefore the best of both worlds to industrials.

In the case of Thermwood, one of the main issues the company is currently addressing, is the reduction of the operator's need to monitor temperatures during the print process.

"Currently a thermal imaging camera is utilized, but this still requires the operator to manually change settings during the print process. Even though modifications are rarely needed, an operator needs to be in place when control parameters need to be modified. We anticipate the operator's participation will be greatly reduced by LSAM control capabilities", the VP of Sales explains.

Reality shows that the production of large parts typically requires hours and even days of printing and trimming. That is why the Thermwood Mobile App has been developed to make it easier for operators to monitor machine processes, program progress, any error messages or any impromptu events that may occur during the printing process.

AND NOW?

Thermwood's long outstanding business has demonstrated that the company has *"the experience, the ingenuity and the building blocks to address Large Scale Additive Manufacturing."* From the M400 - the largest machine it has ever built to increase LSAM production, to the LSAM MT or even the LSAM 1010 3D printers, the company is ready to meet the increasing production demand of companies with very bold manufacturing goals.

This content has been written in collaboration with Thermwood.

OPTIMISING THE METAL ADDITIVE MANUFACTURING WORKFLOW

A look at GF Machining Solutions for post-processing and an eye on medical applications

The big world of manufacturing continuously requires companies to embrace new thinking, new processes and new machinery. With centuries of experience in manufacturing, **Georg Fischer** (aka GF) has dedicated its core business to address the challenges of this universe. Through its three divisions **GF Piping Systems, GF Casting Solutions,** and **GF Machining Solutions**, the Swiss company delivers its services across 33 countries, with 140 companies, 57 of them being production facilities. However, the division **GF Machining Solutions** is the one that draws our attention today. With expertise in EDM (electrical discharge machining), laser texturing machines, milling and an advanced manufacturing unit, the company has been operating in stealth mode ever since it has debuted on the additive manufacturing segment.

Although its extensive experience in machining has helped build its presence in the additive manufacturing arena, like its fellow companies, GF Machining Solutions also relied on collaborations with other AM companies, the most prominent collaboration being the one with 3D Systems. In this continuous quest to address the unique needs of companies that are battling to adopt AM in production environment, the advanced manufacturing unit is continuously making adjustments and improvements on hardware and software environments; improvements in a nutshell that will simplify the path to a seamless and efficient production workflow.

These adjustments also require new solutions for *"a more automated production, thanks to specific tooling products for example– as well as digital transformation which is transversal to all technologies"*, **Romain Dubreuil**, Head of Additive Technologies told 3D ADEPT Media in an interview.

Furthermore, although the company usually talks about it as part of its "integrated manufacturing solutions" and rarely as an individual solution, our conversation with Dubreuil sheds light on specific hardware that has been developed for the much-required **post-processing stages.**

"These stages of the manufacturing process can be split into the 'depowdering' phase and then, into the "finishing" of AM parts by machining operations.

As far as finishing is concerned, we can complement the printing of the part with one of the conventional manufacturing machines in our portfolio. This can be a standard milling machine or a standard wire EDM machine. In many cases, they can fit well, as many operators after the printing stage machine the part to improve the finishing in a certain area for instance", Dubreuil outlines.

As we will discover later on, in the lines below, AM offers so many possibilities for complex implants and biomedical products that 3D printed parts sometimes need further machining and finishing. At this level, workpiece fixturing devices for clamping are often used to process the part and to facilitate subsequent processes.

"We have also developed a specific solution that can cover the needs of AM in this regard", Dubreuil points out.

Named CUT AM 500, this post-processing machine is designed to meet the specific needs of AM and is based on the company's expertise in EDM. Described as an automation-ready alternative to using standard EDM, the process looks like a band saw that separates additively manufactured parts from the build plate. The CUT AM 500 is a good complement to laser powder-bed fusion (LPBF) metal 3D printers.

CUT AM 500 – Image: GF Machining Solutions

CUT AM 500

"Although it has been developed with LPBF in mind, it does not necessarily mean that our portfolio cannot be used for other manufacturing technologies such as Electron Beam Melting or simply metal applications in general", the Head of Additive Technologies notes.

With a size of 510 x 510 x 510 mm, the system allows for the removal of products from large build plates with a weight of up to 500 kg, cleanly and without cutting forces. According to the manufacturer, the process would ensure parts integrity thanks to the tilting table, the horizontal wire EDM process and the customizable baskets. In addition, unlike other post-processing systems, this one enables the integration of a clamping system for easier clamping and referencing as well as automation readiness.

Manufacturing choices

Taking a product from idea to design and 3D printing requires both experience and the appropriate technologies. Although we only focus on post-processing here, let us remind that the ideal AM process includes the entire ecosystem, from quality control processes for incoming powder to software, post-processing, and process controls on finished products. We can never stress this enough but each of these items is crucial to a successful production in highly regulated sectors.

"In general, we focus more on production applications. We are very active in different segments: mould and die, energy and aerospace, industries in a nutshell, where AM can bring benefits to increase performance and weight, and improve parts accuracy. That being said, we also keep a strong focus on the medical industry. One of the major applications in this field remains spinal implants that require technologies that meet the requirements of AM", Dubreuil states.

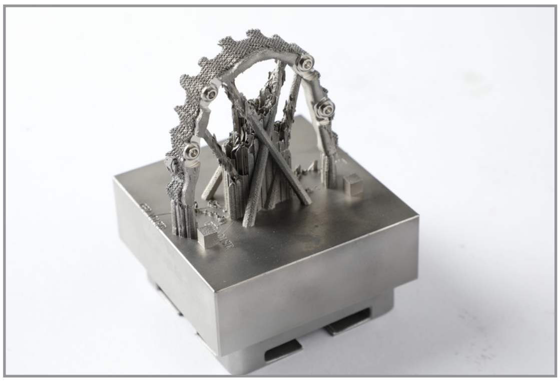
A quick look at the manufacturing of a dental implant.

As applications remain a good proof-of-concept of the way technology works, the Head of Additive Technologies and his colleague **Dogan Basic, Product Manager AM,** share with us a few details on the production of a dental implant as well as several post-processing tasks that can be achieved before getting the desired finished part.

Although we do not know for which purpose the implant has been produced (whether it is for research or commercialization purpose), the manufacturing team used the well-known **DMP Flex 350**, a LPBF-based industrial 3D printer that sported a new look the last time we saw it at EMO Hannover 2019. During the printing process, not only does the system ensure a consistently low oxygen environment but also very high density. We know from the manufacturer that the part has been produced using the **LaserForm® CoCrF7 material** and was printed with 30um layer thickness.

However, what raises our interest the most is the accuracy both in terms of manufacturing time and in terms of post-processing operations.

"It will take 34 min to print one part but obviously, you will print multiple parts at the same time. (9 hours to print 20 parts). We print them on top of our small System 3R BuildPal plate in order to facilitate the post-processing operations. It will take around 23 min to mill each part and just a couple of minutes to separate them with the CUT AM 500", **Dogan Basic** from GF Machining Solutions explains.



As mentioned earlier, complex implants sometimes need further machining. To address this issue, operators can use this equipment called "System 3R" available in a range of pallet sizes.

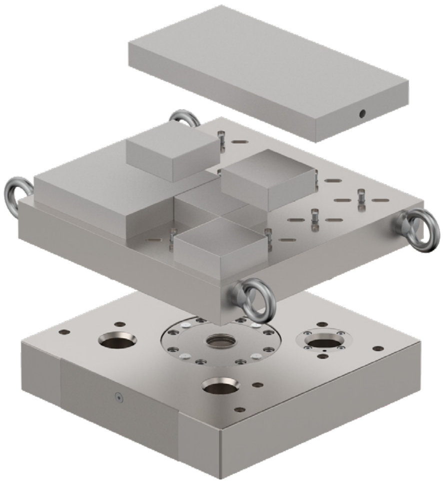


Image GF Machining Solutions

In this specific case, Basic explains that before the milling operation, the part traditionally goes through heat treatment operation and thereafter, through a 5-axis milling operation to ensure that the «connections» are milled.

Thereafter, *"you will have potentially hand finishing to remove potential residual supports and at last, a cleaning operation."*

It is only after these tasks that the implant can be fixed to the jaw.

Concluding Thoughts

Additive manufacturing is certainly one of the technologies where there will always be something new to learn and GF Machining Solutions' perspective in this post-processing segment shows that there is no "one-size-fits-all solution". That is why getting into AM is one thing, and taking the right steps to incorporate its whole process chain is another one, but if it is done well, the rewards one can get can only be substantial.

KEEP DARING

Most of the time, customization is highlighted as one of the major benefits of 3D printing when it comes to 3D printed objects themselves. In such cases, the 3D printing process does not really change. In fact, the process simply consists in the choice of some random items by the customer to get the expected product. However, the focus on the manufacturing process shows that customization can be much more complex than it looks like. A conversation with AMCM GmbH's ***Martin Bullemer*** *and* ***Felix Bauer*** *explains why.*

Creating a business model that works.

Both men met at **EOS GmbH**. With roots in industrial processing, Bullemer has more than 15 years of experience at EOS where he supported the development of the additive manufacturing market in the US and in the medical industry. Bauer on the other hand, is an industrial engineer who joined EOS GmbH six years ago with the ambition to support the growth of AM within the aerospace industry.

At the time, EOS received many requests that almost outlined the same challenge: the need for companies to become more mature while following the path to industrialization. The thing is that **companies with more specific requests often tended to be left apart**.

"Such requests include for instance, but are not limited to the need for different kinds of shapes, different kinds of building envelopes, the need to process copper – a very complex material –, heating from the top and the bottom, and even the need for more powerful lasers", Bauer states.

Rather than just being an expert at developing a new geographical segment for EOS or a specific vertical industry adopting AM, Bullemer saw an opportunity to bring additional expertise on the table, an opportunity to tap into new markets, to create new revenue streams and expand product offerings.

Although the idea was brilliant, it also raised several questions and uncertainties. *"Those requests that were often left apart mostly require further customization. Although we wanted to address their challenges,*

image credit : AMCM GmbH

we did not know how big the market was. Furthermore, when you are a big company, you cannot develop a new company with the same flexibility than with a start-up; you cannot start a new technology development just to market ten systems, you cannot start the development of a machine when you are not sure somebody will pay for it", Bullemer emphasizes.

All those "what-ifs" made sense. Although, we should recognize leading companies' go-to-market capabilities, it was simply too risky to afford to meet each unique demand with a new 3D printer. That's why 2017 saw the creation of **AMCM GmbH** which stands for **Additive Manufacturing Customized Machines**. As the name implies, the company is born with the goal to provide industries with customized LPBF *(Laser Beam Powder Bed Fusion)* machines from EOS.

At the time we write these lines, Bullemer is Managing Director at AMCM GmbH and Bauer is currently Regional Director EMEA | DACH/NL at EOS and in transition phase to join AMCM GmbH full-time.

Innovation and entrepreneurship can come in many shapes and sizes.

Unlike industrial 3D printers from its fellow machine manufacturers, we cannot legitimately describe all the features developed in an industrial 3D printer from AMCM GmbH – and with good reason: "***we focus on applications**. A customer comes to us with a specific request and we work on a solution that might fit a specific need. Obviously, over time, we came to realize that some needs might be easier to fulfil than others. For instance, we received a lot of requests for machines with customized build sizes. These are relatively easy use cases because they require mechanical engineering tuning, not to mention the fact that you do not have to change the entire process"*, the Managing Director explains.

"Every machine manufacturer has his standard portfolio, which might fit or not to the application of the customer – at least to a certain degree. At AMCM, we take a very close look at that application and make the machine fits into that. Of course, sometimes, the standard solution is good enough for the customer, but for those who need that 'extra thing' that will make a difference in their projects, for them, AMCM comes into play", the regional director completes.

Martin Bullemer

As we discussed the requests they often received from their customers, we came to realize that the question is not about the number or the type of requests they are able to manage, but above all, what makes them outstanding. Trivial but crucial.

From system requirements, part design to material development and beyond, additive manufacturing systems require a lot to process, but some functionalities are just more pivotal than others. It is for instance, the case of laser and optical features that require extensive knowledge in the development of a machine. At AMCM, half of the team is coming from the laser industry. "We definitely have an expertise in laser tuning – different wavelength, different laser types – and in the selection of the right optical set-up, which is a key component in every additive manufacturing machine", Bullemer notes.

Furthermore, although an inquiry from AMCM might lead to the development of a dedicated depowdering solution as we saw with the Solukon's SFM-AT1000 machine, it should be noted that each industry 3D printer does not necessarily require a dedicated post-processing equipment. As a matter of fact, at the end of the day, it's up to the customer to decide what depowdering or powder handling solution he will go for.

Thereafter, comes the **question of price.** Countless examples in the automotive industry show that luxury vehicles provide increased levels of comfort, equipment, amenities, quality, performance, and status relative to regular cars for an increased price. Although "luxury" might be a quite subjective term, the fact remains that car manufacturers that develop vehicles with an unusual level of performance have created a separate brand for them and commercialize these vehicles at a price that is not always seen on the standard market.

In a certain sense, this very-much understandable theory can be applied to the manufacturing industry. As per the words of Bullemer, *"customers-dedicated machines are not often commercialized the same way that conventional AM machines, therefore, unlike their fellow machine manufacturers, manufacturers of customers-dedicated machines do not often have the benefits of a very well-established supply chain. Indeed, the less you build, the more costs you have. Furthermore, every modification requires an engineering effort that needs to be balanced. In the same vein, a customer can come with a unique crazy idea in mind. Once we have developed a solution for this idea, the chances are very high that we will no longer sell the same machine to another customer. In principle, these machines are always a little bit more expensive than the others but we make things possible and our customers only buy if their business case is working."*

Combustion chamber - Image: AMCM

Efficiency, measure of throughput?

"...only buy if [your] business case [works]." Bullemer's statement emphasizes that price is just one element of the story. Most importantly, **it outlines "efficiency" as measure of throughput and refocuses the debate on applications.**

The ongoing race for space for instance has seen a boom in satellite applications. Although this industry is a very conservative one, the past years saw applications that are due to the combination of a wide range of technologies, not just additive manufacturing. According to Bauer, *"young engineers do no longer rely on what has been done before, they have a much wider range of choices when it comes to production and there is a certain demand on the market for such needs. Plus, a close look at the market shows that the private space is the one that actually drives the industry."*

In the private space business, commercial motivations require to focus on the highest performance at the lowest cost. And one way to bring this utopian winning formula closer to its reality is to bring metal AM in the game.

"Rockets are the perfect example of such cases as they require unparalleled efficiency for commercial space deliveries", Bauer stresses. If you are an aerospace engineer, it is certainly no secret to you that propellant is often the heaviest part of a launch vehicle's mass (up to 90% of a launch vechicle's mass). Therefore, reducing propellant use leads to further opportunities to reduce vehicle mass, therefore to increase payload and performance for the same rocket size. But these are just one element of the manufacturing process. *The point is, those "rocket parts are very complex to manufacture. [While lightness and robustness are two pivotal factors that can be improved through AM,] it should be noted that these parts always need to be achieved within very short-lead times.*

Felix Bauer

Most importantly, they require a machine that can easily enable iteration, reinvention, reproducibility and a smooth process to the next stage of manufacturing. At the end of the day, that's the most important", Bauer continues.

One example that illustrates this argument is the recent achievement of New-York-based startup Launcher. During the last quarter of 2020, the space company started testing its full-sized E-2 liquid rocket engine, a technological progress that paves the way to more affordable and high-performance solutions for smaller space launch vehicles.

"Launcher has influenced the design of our machines. The challenge was to demonstrate that we could print a one metre tall single-piece copper alloy combustion chamber, an area where companies do not have much expertise in. It's a huge challenge because there is a high-risk of failure when you try it the first time. Such production requires a good know-how about AM and the Space startup had just started to design for AM and they were really depending on the right know-how to make their ideas come to life. The next step is to get funding to accelerate development of this E-2 engine", the Managing Director, points out.

We learned that such parts are typically 450 x 450 x 1000 mm in dimensions, they are made out of **CuCr1Zr** and feature intricate internal regenerative cooling channels, hence the need for a dedicated system capable to process this type of material. To make it happen, the company finally used its AMCM M4K 3D printer and tested the parts at NASA Stennis Space Center.

"That's the beauty of being a startup", Bullemer adds. Not to mention that *"you have a bunch of people who share the same vision and the same willingness to achieve it"*, completes Bauer.

"We make it happen"

"We make it happen." How many times have you heard these four words before realizing that a lot is promised and little is actually delivered. Today, while looking at AMCM's business model, the precautions the team took before its implementation and above all the applications they are achieving, I am ready to take their words for it.

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CURRENT ADVANCEMENTS & EXISTING HURDLES IN DENTAL 3D PRINTING

Image: kfadental.com

Although dentistry has long time been associated with subtractive manufacturing – milling especially – , a report from market intelligence firm CONTEXT reveals that this field makes up over one fifth of the end market for professional polymer 3D printers (5,000 USD upwards). Despite the significant improvements made to advance the use of AM within this field, some technological and cost impediments still raise a number of questions among experts. This feature will discuss these advancements and the improvements that still need to be made to enable a wider adoption of AM technologies in the field. To discuss this issue, ***Stijn Hanssen*** *– Sales, Marketing & Applications Manager at 3D Systems and* ***Mayra Vasques****, founder of Innov3D have been invited to share their insights into the topic. Hanssen will share the point of view of a 3D printer manufacturer whereas Dr. Vasques will bring the user's perspective on the table.*

No exact figures reveal the number of dentists and dental technicians who are well acquainted with digital manufacturing technologies. Nevertheless, over the past decade, developments in computer technology and software applications have facilitated the adoption of 3D printing.

With a dental 3D printing market poised to reach 9.5 billion USD by 2027, it is easy to understand the increasing investments in the development of dental 3D printers from manufacturers and the willingness of clinics to improve the way they provide care. Despite the options they have, the choice of manufacturing tools may vary from one clinician to another.

Main manufacturing tools used in a dental lab

From a technological perspective, the use of digital manufacturing technologies in dental labs started by the adoption of a dental 3D scanner to provide an accurate 3D model. As you may know, 3D printers are nothing without a computer-aided design (CAD) software, but all clinicians do not always have the required knowledge to virtually design a model.

Today, several routes are offered to surgeons and dentists who have ready access to volumetric data in the form of computed tomography (CT) data, cone beam computed tomography (CBCT) data, and intraoral or laboratory optical surface scan data. On the other hand, with the number of affordable dental 3D printers that are popping up, manufacturers increasingly develop more user-friendly software to support these users, thus questioning the role of a dental 3D scanner in the dental lab. According to Hanssen:

"dentistry is going through fundamental changes, starting with analogy and moving towards digital workflows with digital scanning, design, 3D printing materials. Traditional lines are being blurred in the dental field. We think that most dental care providers will find the use for an intraoral scanner as a more accurate and convenient alternative to analogue impression materials. For the scanning process there are several options depending on the clients' case; scanning an impression or intra oral scanning. Key is what is done with the scan afterwards. The accuracy in design and in printing is very important for a better patient outcome."

As a user, Vasques believes that a dental 3D scanner continues to have a unique role to play in the digital workflow:

"The digital workflow in dentistry consists in 3 steps: data acquisition, design, and manufacture. I´m used to explain this as, first you must transform the real into digital by data acquisition then you will be able to create your project using the design software and after that you will turn this virtual project into reality using digital manufacturing. Affordable dental 3D printers make it possible to spread this technology in dentistry and improve the in-office 3D printing modality, but they are not a substitute for the 3D scanner, each one belongs to a different part of the process."

Apart from dental 3D scanners, let's note that 3D printers have also come a long way. Currently, dental applications and collaborations between companies show a key focus on the use of **liquid-based 3D printing technologies such as SLA and DLP**. Each of these technologies offers its pros

Mayra Vasques
founder of Innov3D

and cons, so the ideal choice often comes down to the taste of the chef in the kitchen. We strongly recommend to have a look at this exclusive article on the secrets of resin 3D printing if you consider buying a resin 3D printer.

In terms of technologies, other professionals often go for **photopolymer jetting (PPJ)** – another form of resin-based 3D printer –, **powder binder printers (PBP)** which use a modified inkjet head to print, using what is essentially liquid droplets to infiltrate a layer of powder, layer by layer. Other choices also include **SLS** and **FDM**. Metal 3D printers on the other hand, often lack the precision that is required of dental models. Moreover, due to their expensive cost, most clinics do not often consider it as a viable option.

Speaking of the main tools a clinician may use before and after the printing process of a model, Vasques explains:

"The ideal process requires an intraoral scanner to obtain patients digital cast and a resin 3D Printer (SLA or DLP technologies) due to accuracy and the different options of biocompatible resins. To complete the process successfully, it´s necessary to carefully proceed the post processing method washing the printed parts properly and post-curing to reach the best characteristics of the materials."

Applications and production

Applications in dentistry are extensive. Two of the most common applications of 3D printing in the field are **transparent aligners** and **night guards**. Others include but are not limited to **crowns** and **bridges, temporaries, surgical guides, splints, try-In, dentures, and gingiva masks** – According to the founder of Innov3D, all these products can be divided into two categories:

"The first category comprises products that will be used over a long period of time inside the mouth. They include for instance dental prosthesis, aligners and night guards. The second category comprises products intended for procedures. They include surgical guides and a wide range of other guides such as bio models and customized instruments. There is a lot of room to innovate to create new techniques and new solutions".

Despite the variety of applications that can be achieved on **3D Systems' NextDent® 5100**, the company's Applications Manager notes that some 3D printing solutions stand out from the crowd.

Stijn Hanssen
Sales, Marketing & Applications Manager at 3D Systems

"We see a big utilization of 3D printing for temporary or final prosthetics. Dentures have also been an incredible growth market since last year and night guards are gaining popularity." Moreover, according to the manufacturer, **orthodontic tooling models for thermoforming** are the applications that require volume production the most.

Legend: Models printed on NextDent® 5100

In a more complex environment, it should be noted that one of the earliest applications of 3D printing in surgery – **medical modelling** – has opened up more possibilities for dentistry in recent years. CBCT (Cone-beam computed tomography systems) has become widely available in dental practices and has revolutionized the way diagnosis and treatment are performed in implant dentistry and endodonctics.

Thanks to CBCT, it is possible to provide volumetric 'image' data to a 3D printer before surgery and to make detailed replicas of the patient's jaws for instance. In a nutshell, this process enables the practitioner to analyse more precisely complex, unusual, or unfamiliar parts of the anatomy, therefore to better prepare prior to the theatre room.

All these applications lay emphasis on the advantages of additive manufacturing (AM) when it comes to **customization,** and the technology's ability to meet the same quality and precision seen in other industries. However, even though for now, there are not many applications that require volume production, we couldn't help but question ourselves if this would not be a challenge in the long-run.

Challenges and future outlooks

Reality shows that it is easy to talk about volume production in other fields of manufacturing. Slowly but surely, the market is growing at its own pace. Therefore, the more the demand will grow, the more dental labs will envision equipping their clinic with a 3D printing farm. In those situations, Vasques believes that manufacturers will need to improve the logistics and equipment so that the clinician spends less time on the floor.

In the meantime, she states that the current area for improvement should be the **type and quality of materials for long-term intraoral use**. *"Dental professionals are more and more open to new technologies, but most of them relate that they are not secure with the longevity and safety of the 3D printed parts"*, she adds.

On the other hand, as 3D Systems is working on new materials and 3D printers' development, Hanssen points out the need for **education** and **training** to help advance the utilization of 3D printing among clinicians and dental specialists.

"Dental 3D printing will play an important part in the digital future of dentistry as 3D printing materials will become more advanced and the number of applications will grow. Due to Covid-19, we all aim to assist dental practices to reduce contact with patients. Working with digital patient data helps to reduce patient chair time and improves safety for both patient and practise", he completes.

Lastly, despite this growing acceptance of digital manufacturing technologies in the field, one notes that the national regulatory bodies have not yet implemented guidance in the use of 3D printing in dentistry. At some stage, regulators will certainly need to set appropriate standards that will facilitate the use of these technologies among specialists.

About the contributors

Mayra Vasques works for **Innov3D**, a medical company that is on a mission to accelerate the adoption of 3D technologies in dentistry. The team believes that the great potential in dental market is in the hands of the new generation that is being trained in universities. Their services include online nanodegrees about selected dental topics, faculty training to transform didactic materials to digital ones, and to support universities and institutions as they transform their spaces for new classes and equipment.

Stijn Hanssen is Sales, Marketing & Applications Manager at **3D Systems**. The company offers both small and big dental labs and clinics a selection of complete digital dental solutions to match their specific requirements; from entry-level dental 3D printers and mid- and large-platform batch 3D printers, to rapidly scalable workflows, materials and software.

Even smaller practices can benefit from using a digital workflow or outsourcing to a lab with 3D printer because of the higher speeds, accuracy and lower costs.

ADDITIVE MANUFACTURING SHAPERS

BEHIND THE SCENES OF « THE SPACE RACE » WITH VIRGIN ORBIT

With private companies at the forefront of recent space innovations, the space industry is undergoing a paradigm shift driven by disruptive market solutions offering and industrial approaches that were not often considered by governments. What is interesting in this new paradigm is that it opens up new doors for technological innovations and position space new entrants as experts across other vertical industries. In this vein, 3D ADEPT Media discusses the current use of additive manufacturing technologies at Virgin Orbit and some of the challenges the Space industry faces in the adoption of these technologies.

Three years ago, **Virgin Orbit** debuted on the very select small satellite business with the goal to provide the most flexible and responsive satellite launcher ever invented. To achieve this mission, the Virgin Group company had been working on a **LauncherOne smallsat rocket**, an air launch to orbit rocket, designed to take smallsat payloads of 300 kilograms (660 lb) and more into orbit.

After an unsuccessful first attempt, the space start-up finally lived up to its name since on January 17th 2021, it reached orbit, successfully deploying 10 CubeSats into Low Earth Orbit. The milestone was even important for the space expert as **it was the first time it launched working satellites into space on behalf of NASA.**

Although the successful launch is due to a technique called **air launch****, it should be noted that if the *provider of launch services for small satellites* is becoming a high-profile pioneer of this new commercial space race, it is also because at the heart

of some of its manufacturing projects, additive manufacturing has always been recognized as a key enabler.

"At Virgin Orbit, we aim to contribute to the future of humanity in space. We help our customers change the world by increasing the rates at which we make our rockets while reducing the cost per launch. To do so, we rely on advanced manufacturing techniques and technologies to manufacture propulsion components as well as other complex components that can be embedded in a rocket, **Oluseun Taiwo**, Propulsion Advanced Manufacturing Engineer, states from the outset.

Virgin Orbit first appeared in our radar when NASA Marshall Space Center announced that, together, they should explore multi-metal 3D printing to build multi-metallic combustion chambers.

The project was even more important for the team at Virgit Orbit, as information gained from this partnership would be key in applying AM *"technologies to further improve cost, performance and lead time of [its] propulsion systems for the LauncherOne vehicle."*

Multi-metallic parts are a significant improvement in the production of rocket engine combustion chambers as they mainly address materials properties requirements (such as strength or thermal conductivity) – requirements that Virgin Orbit has been able to meet in this case using an in-house **hybrid additive-subtractive manufacturing system.**

This being said, we have noticed that **Powder-bed fusion** and **DED AM technologies** are also often very highlighted as one of the most used AM technologies in-house - especially for the production of intricate details and cooling channels into **thrust chambers** and **injectors**. When asked the reasons why they focused on these technologies, Taiwo replied:

"DED allows us to make massive parts very quickly. The deposition rates that you make on those machines are quite quick. It would be hard to find another AM process that can beat DED processes in terms of uniformity when it comes


Oluseun Taiwo, Propulsion Advanced Manufacturing Engineer

to production of massive parts. DED also allows us to create multi-material solutions for very hard processes. For instance, you can get a weight saving in some crucial parts while in others you can get some performance upgrades using this process.

Powder bed fusion on the other hand, allows for the creation of some intricate geometries in high quality, not to mention that it can also process a lot of materials. We often used this technology for the manufacturing of complex thrust chambers with cooling channels or turbo machinery. With thrust chambers that feature cooling channels for instance, it's a great time saving to be able to manufacture such parts in one go", the engineer explains.

The main complexities in the use of AM in space.

Low-cost satellites and lighter rockets are usually mentioned as one of the first AM applications in the space industry, but we are still far away from a "natural" utilization of AM. Indeed, engineers still have several manufacturing challenges to overcome.

For space ventures to easily launch satellites, probes telescopes or spacecraft in orbit, they need to address the high per kilogram cost required to break free of the Earth's gravitational pull.

In other words, mission costs can be expedited by several orders of magnitude for every additional kilogram of payload. **Weight** is definitely the first challenge AM is uniquely positioned to overcome but others come inevitably into play.

According to Taiwo, **materials uniformity** is on top of the challenges space engineers usually meet during manufacturing. *"We need to be able to produce repeatable propulsion or structural components which can be very complex depending on the manufacturing process used. Complexity relies on several factors and we should be able to capitalize on manufacturing and produce hardware that will not only work one time"*, the engineer says.

Furthermore, as we saw in most industries, Taiwo outlines ***"Design for AM"*** as another complexity in the use of AM in the Space industry. Reality shows that space applications such as launchers and satellite systems are produced in small batches but they must cope with the extreme conditions and requirements of launching, not to mention that they can be used for more than 15 years after successful orbit insertion.

Unlike other industries, *"metal AM is still in its infancy in this field. From an engineering design perspective, AM increases the opportunity to apply new software strategies such as topology optimization [as it offers the opportunity to manufacture with minimal weight by solving material distribution problems]. From a design perspective, we are not yet there. In general, space engineers are still trying to understand where they should push in their designs to better control the manufacturing process. However, I like the approach we have at Virgin Orbit, as we innovate as much as possible by asking questions and scrutinizing processes We bring technologies in-house and we spend time on development – and any time, there is a certain change, we are going to treat it as a whole new process. That conscious step, for some people, it does not work but for us, it does."*

This DfAM challenge in space applications has been confirmed with other space engineers. As a matter of fact, for most engineers, designing in additive manufacturing is difficult because it involves a process of unlearning the design guidelines from conventional manufacturing. Furthermore, existing AM processes reveal a variation in the printed products, which can vary from one part to another or from one machine to another.

There are several different approaches available for DfAM and as we understood from Taiwo's comments, there is not yet a defined guideline that can be used by all companies. However, one method often used by designers is to define AM candidacy through the **design**

analysis approach. This approach consists in identifying parts where AM could be applied efficiently by leveraging DfAM capabilities. Four criteria are often taken into consideration in this process: **functions integration, customization, lightweight design as well as operation efficiency.**

The user perspective vs the anufacturing perspective

As an early adopter of AM technologies in the space industry, Virgin Orbit is also uniquely positioned to raise some of the questions that still need to be discussed by AM vendors and AM service providers.

According to our guest, one of these concerns is the fact that, although AM is a very highly automated process, there are still features such as powder removal/parts cleaning that are not automated. Any space company that is looking to increase its production and launching pace will look for ways to control and automate this manufacturing stage.

As time is going by, the space sector will take an even more important place in the additive manufacturing industry. Virgin Orbit's very strategic use of AM to provide launch services for small satellites is a good illustration of the way a space company can leverage these technologies. Whilst the development of combustion chambers and injectors by AM are very unique, the present story sheds light on some of the complexities that still need to be addressed at the manufacturing level; complexities that will certainly require further collaborations between AM technologies providers and space companies to enable further commercial launches.

***At the heart of Virgin Orbit's successful launch is a technique called, **air launch** – that provides more versatility for space missions, since the carrier airplane can be based at any airport that has a runway long enough for takeoff. A technique, in a nutshell that improves the payload capacity of the rocket, and makes the LauncherOne system one of the most flexible and responsive launch service of the market.*

THESE UNUSUAL 3D PRINTING MATERIALS

3D printing has led to some of the coolest objects we have ever seen in this industry but sometimes, the materials used to produce these objects are fabricated in a very unexpected way. 3D ADEPT Media looks at some of the strangest materials, industrial AM companies, scientists and makers have discovered over time. From industrial applications to "Do-it-Yourself" applications, these innovations can meet the simplest needs of industries to the most urgent needs of the planet.

Edited by 3D ADEPT MEDIA

Rotary Aomtzier in Use.

Enrico Gallino
Senior Engineer – Material Specialist Additive Manufacturing at Ricoh UK

Sometimes qualified as "strange" or "unusual", these unique materials are not less efficient. On the contrary, the innovators behind these materials have proved to advance the 3D printing industry in their respective field of expertise. We would like to outline today **5 materials**, their unique properties and (at times) the atypical way they have been developed.

1 – Keep it clean.

One of the complexities of a technology is making it compatible with "vital products", in other terms, products that can affect our health if they are not safely produced.

Take for instance a single water fitting. For a part that looks trivial, all it takes is a bad installation or a production with the wrong materials for a disaster to strike.

As we were researching our list of unusual materials, we came to realize that 3D printing has something offer for such type of production. In fact, 3D printing company Ricoh has developed a new powder called **Ricoh Polypropylene** that could be used to address the needs of parts production that can be in contact with water for instance – as well as for applications in the industrial and energy sectors.

Approved by the WRAS (Water Regulations Advisory Scheme), the 3D printing powder delivers high flexibility and good impact resistance. It has successfully passed rigorous tests to ensure that:

" – it doesn't affect the quality of water by changing its appearance, taste or odour;

– it doesn't leach toxic compounds and heavy metals which may be harmful;

– and it doesn't promote the microbial growth within piping removing therefore the risk for generating unsightly slime formation."

"Combined with its chemical stability and water tightness, parts produced with our polypropylene material are an ideal solution for producing functional prototypes and serial components for applications in contact with water" **Enrico Gallino**, Senior Engineer – Material Specialist Additive Manufacturing at Ricoh UK comments.

2 – Space exploration

Let's explore a little bit more what may happen in space. The following plastic material is a combination of **Polyetherimide/Polycarbonate** (PEI/PC). It is definitely among the 3D printable tools that brave the vacuum of space.

As you may guess, tools within the station are quickly limited to repairs – given the harsh conditions of the environment. This plastic material developed by Made in Space (MIS) would address this challenge as *"it is not going to emit particles in a vacuum, it's resistant to the UV environment, it's resistant to atomic oxygen, so it can perform actual uses in space."*

Most of you are certainly aware of blends of PEI/PC, such as ULTEM 9085 and ULTEM 1010, which are used in additive manufacturing for commercial aerospace applications. On earth, one could easily see PEI/PC being adopted in aircraft cabins and in the medical industry. Having nearly triple the tensile strength of ABS, a high strength-to-weight ratio and low off-gassing properties, PEI/PC is the ideal candidate for external hardware and satellites in space.

As MIS' President & CEO said during the launch of this material: *"Manufacturing in PEI/PC really expands the value of in-space manufacturing for human spaceflight. PEI/PC is a truly space-capable material. With it, extra-vehicular activity (EVA) tools and repairs, stronger and more capable intra-vehicular activity (IVA) tools, spares, and repairs, and even satellite structure can be created on site, on demand. That enables safer, less mass-intensive missions and scientific experiments."*

This list is not exhaustive but we hope you get the overall point: 3D printing might be one of the rare manufacturing processes – if not the only manufacturing process – where we can expect the unexpected.

3 - Turning human waste into a 3D printing material

Just when we got used to pay attention to objects that can be recycled and turned into 3D printing materials, we learn that there is a tiny chance to turn human excreta into 3D printing material.

This extraordinary solution is the idea of fourteen students from the University of Calgary in Canada who competed two years ago at the International Genetically Engineered Machine (iGEM) Foundation's Giant Jamboree on the theme "synthetic biology".

As the title implies, "Astroplastic: From Colon to Colony", their project involves the use of human excreta as a major bioplastic ingredient for 3D printing in space. The reflection behind this idea is a really interesting one as many aerospace professionals will tell you the numerous challenges one can have to produce a functional tool that meets the harsh conditions of the space environment not to mention the transportation when resources are lacking.

Plastic wrench

As part of this issue of 3D ADEPT Mag, we reached out to **Alina Kunitskaya**, one of the leaders of this project to have further information about its advancement :

Could you please explain the process of using human waste for creating a 3D printing material?

Our project called "Astroplastic" aims to address two major challenges with future human missions to Mars: sustainable waste management and the high cost of shipping materials to space. In our system, poly(3-hydroxybutyrate) bioplastic, or PHB for short, is produced by genetically engineered Escherichia coli bacteria that use volatile fatty acids found in solid human waste.

To describe the proposed process in more details, astronauts' feces are first collected into a storage tank using a vacuum toilet. Feces are then transferred into another tank and left to ferment for 3 days with bacteria naturally found in human feces to increase the concentration of volatile fatty acids. Next, the liquid containing volatile fatty acids and other nutrients from human waste is separated from solid particles using centrifugation followed by filtration. The obtained volatile fatty acids are then added to a fermenter containing the engineered PHB-producing E. coli. Lastly, PHB produced by bacteria is extracted from the liquid harvest stream and dried, resulting in the powdered bioplastic material.

Did you go to the end of the experience to discover what kind of objects (flexible, solid, etc.) - and on which AM technology -one can print such type of materials?

We expect that the produced bioplastic can be used to print solid objects. In particular, we hope astronauts will be able to use it for printing tools and small items that may be used as spare parts for maintenance repairs or science experiments. Since the final product is a powdered plastic material, we considered using selective laser sintering as the most suitable AM technology. However, our experiments have been done on a small scale so we didn't have enough material to test the use of produced material in selective laser sintering so far.

How different would this 3D printable material be from other materials we usually used for 3D printing?

Although PHB has been used in 3D printing before, it can be quite brittle. We would need to further investigate if there is a need for post-processing of the produced bioplastic to create a blend with suitable properties.

What is happening with the project "Astroplastic: From Colon to Colony" so far?

We were able to successfully engineer E. coli to produce PHB bioplastic, which was tested using a simulant of solid human waste. Since bacteria naturally produces PHB granules internally, we also engineered bacteria to secrete the produced PHB for easier extraction. In parallel to these biological experiments, we also developed a concept for a start-to-finish PHB production process on Mars based on feedback from experts, determined optimal operating conditions for several steps, and tested several steps in the lab. This project was presented at the International Genetically Engineered Machine (iGEM) competition, receiving a gold medal and a nomination for Best Manufacturing Project.

Following the iGEM competition, we also investigated how to adapt the proposed process to the microgravity environment (as the initial process was developed for the Martian gravity environment). In particular, we tested the plastic extraction step of the process in microgravity aboard a parabolic flight.

Is there a one-way guide to determine if a product can be used as good feedstock for creating consistent filament?

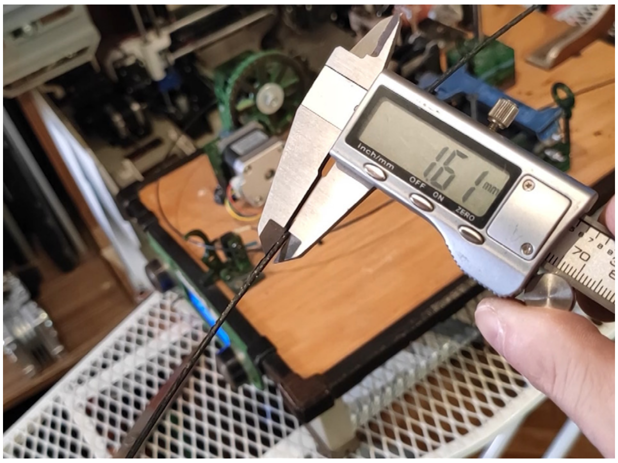
As a student group, we had limited resources and expertise to test the use of our product. At this stage of the project, we relied on existing literature involving our product or similar type of products (powdered plastic material) to determine the feasibility of using this material and to identify suitable AM technologies.

4. Keep tape from Old VHS Cassettes for your 3D printing filaments.

If you are part of generation X or Y, then you are certainly familiar with VHS, which stands for Video Home System, a standard for consumer-level analog video recording on tape cassettes. With all the streaming platforms that are available today, these tape cassettes have become quite obsolete.

Rather than throwing them away, Russian maker **Andrew aka Brother** has given a second life to all of that tape. With the goal of making the planet cleaner, Brother has been experimenting several materials made up of different objects: plastic bottles, Christmas tinsel, medical masks, dvd discs, Styrofoam – most of them are even shared on **his personal YouTube account**.

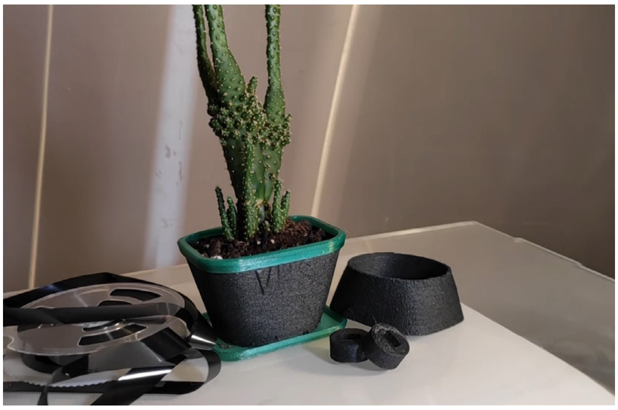
"I want to save the planet from garbage, at least a little. I think that if many people repeat my experiments, the planet will become cleaner. Passing by the landfill, I saw over 100 VHS cassettes. At first, I thought I would use cassette casings, but I finally decided to try melting the tape", he told 3D ADEPT Media.



With four to five layers – one being magnetic –, Brother explained it is easy to remove tape from a VHS by pushing a button on the top left of the cassette. Once it pops the top open, you need to press down in the middle of the back of the cassette to unlock it before you can unwind all of the tape.

To create the filament, the maker used a purpose-built press to tightly spin the tape from several cassettes into one strand of 3 mm filament. This stage requires several tests to make sure the strand did not end up being too thin.

"The tape filament needs to be heated higher than a standard 3D printer filament so he prints at a much slower rate, but the resulting product is indistinguishable from a normal print except for the color," Bryan Cockfield stated in the Hackaday post. "It has some other interesting properties as well, such as retaining its magnetism from the magnetic tape, and being a little more brittle than PET plastic although it seems to be a little stronger."



After several tests on his Omni 3D printer, the maker noted that filament is quite strong and delivers prints with a smooth texture. However, when asked how different is this 3D printable material from other materials he usually used for 3D printing, he said:

"I usually print with unusual materials which are recycled plastics. Therefore, I cannot compare such materials with 3D printing materials used in factories. The VHS filament is interesting in that it has electrical conductivity, although it delivers high resistance, and magnetization. Post-processing is unnecessary for this material. The printed objects have a very nice structure. There are not many tapes left in the world. And of course, such a filament production technology cannot be introduced into mass production, but you can peep the composition of the tape and create a factory filament on its basis."

5. Inspired by nature.

While construction 3D printing provides a wide range of benefits for the building industry, one of the most important challenges builders face is with materials. Researchers keep exploring the materials possibilities for this specific segment and have already come out with some unexpected ideas to print structures in the construction industry. One of them includes fly ash - a residue from burnt coal.

However, if we write these lines, it's to address one of the challenges raised by one of the most used materials in construction 3D printing: concrete. Except that this time, we'll talk about **lobsters and concrete**.

The truth is, making concrete strong enough for complex, creative structures is a holy grail for builders. A team of researchers from RMIT University has recently explored the natural strength of lobster shells to design special 3D printing patterns.

Needless to remind that what makes these marine crustaceans outstanding in the eyes of ordinary people is their muscular tails. However, a thorough analysis of scientists revealed that lobsters present bio-mimicking spiral patterns that could improve the overall durability of the 3D printed concrete. Furthermore, the aforementioned patterns could also enable the strength to be precisely directed for structural support where needed.

When the team combined the twisting patterns with a specialised concrete mix enhanced with steel fibres, the resulting material was stronger than traditionally-made concrete.

Speaking of the benefits of bio-inspired approach in 3D concrete printing, lead researcher **Dr Jonathan Tran** said: *"We know that natural materials like lobster exoskeletons have evolved into high-performance structures over millions of years, so by mimicking their key advantages we can follow where nature has already innovated."*

The team tested the impact of printing the concrete in helicoidal patterns (inspired by the internal structure of lobster shells), cross-ply and quasi-isotropic patterns (similar to those used for laminated composite structures and layer-by-layer deposited composites) and standard unidirectional patterns.

The results showed strength improvement from each of the patterns, compared with unidirectional printing, but Tran said the spiral patterns hold the most promise for supporting complex 3D printed concrete structures.

"As lobster shells are naturally strong and naturally curved, we know this could help us deliver stronger concrete shapes like arches and flowing or twisted structures," Tran said.

"This work is in early stages so we need further research to test how the concrete performs on a wider range of parameters, but our initial experimental results show we are on the right track."

Further studies will be supported through a new large-scale mobile concrete 3D printer recently acquired by RMIT – making it the first research institution in the southern hemisphere to commission a machine of this kind.

There is a still a long list of unusual & strange materials used in the additive manufacturing industry but those five materials are the ones that raised the most our interest, for now. If you believe that another material should absolutely be in this list, please, feel free to let us know.

COUNTRY FOCUS : THE NETHERLANDS

*In our ongoing efforts to provide companies with information that will help them take a leap into a new market, this volume of 3D ADEPT Mag will focus on **"The Netherlands"**. It will highlight a state of the art of the AM market in the country as well as the different business approaches applied to position oneself on this market. Last but not least, it will also highlight the current AM projects in progress within AM companies.*

Known as the "gateway to Europe", the Netherlands is often described as a well-connected business location. Its geographical location in continental Europe makes it easy for professionals to access major European economies, like Germany, the United Kingdom, Belgium, France, in less than a day. While the country is ranked as the fourth-best nation for innovators by the EU Innovation Scoreboard 2020, "Invest in Holland" reports that companies that are mostly attracted to the country come from the **IT, Creative and Chemical**, as well as **Life Sciences & Health industries**. This can be understandable given the long-established benefits of these sectors for economies.

As far as AM is concerned, no defined date announces the first steps organizations take in additive manufacturing. However, research shows that the beginnings of additive manufacturing in the Netherlands were observed in the 1990s, when **Janne Kyttanen**, a creative and industrial designer had a vision of finding a better way to design, manufacture, store and distribute products using 3D printing. With 25 years of experience in 3D printing, it is fair to say that Kyttanen knows a thing or two in the 3D printing industry. He was not a casual observer of the trends that marked the manufacturing industry in the country. He took part in this manufacturing revolution by creating ***Freedom of Creation*** – with the support of Belgian 3D printing company Materialise; a company that he defined as an "applications company" and that was acquired by 3D Systems in 2011.

"That time was about trying new business models that would have improved past processes. At that time, the word 3D printing was barely used. The goal was to show that there was a better way to design & manufacture products", the designer told 3D ADEPT Media.

Then came the 2000s, a period that saw the launch of several other 3D printing companies that have managed to position themselves on both the global and local additive manufacturing scenes as leaders in their field. They include for instance: **Shapeways** (2007), **Ultimaker** (2011), **Additive Industries** (2012), **3D Hubs** (2013) to name a few of them.

Apart from Additive Industries that focused on the industrial market from day one, it should be noted that those companies that contributed to the advancement of the manufacturing market and its transformation from 3D Printing to AM, laid good foundations **through 3D design, 3D model marketplaces, fab labs** as well as **independent printer hubs**.

Janne Kyttanen
Creative and industrial designer

While looking at the manufacturing industry, Kyttanen realizes that *"the Dutch government has always been quite similar to Brussels' one. It is a government that supports forward-thinking technologies*

Photo by Andrea Kratzenberg

and arts. [By "arts", understand the ability to create and apply a new technological concept] as the mindset is very engineering-driven." He also recognizes that *"technology has no value if one does not know what to do with it hence the crucial combination with vertical industries to make a better impact in the country."*

Furthermore, it is hard to say if a causal relationship should be established but the designer also outlines the fact that geographical proximity of technology companies might lead to the development and implementation of others in the country – as compared to Los Angeles where he needed to drive up to four hours to find a technology company.

Major sectors of activity for AM in the country

Despite the laudable advances in the field, a great number of AM activities remains in **the R&D arena**. Indeed, **universities and research institutes** are a major contributor to the number of Dutch 3D printing technology-related patent applications, accounting for 21% of the total European applications according to the European Patent Office (EPO)'s report. The country is currently **the fourth applicant in terms of patent applications for 3D printing technology**, after Germany, France, and the United Kingdom. Furthermore, within regions, the **Eindhoven** city ranks fifth, after Munich, Barcelona, Zurich, and Berlin.

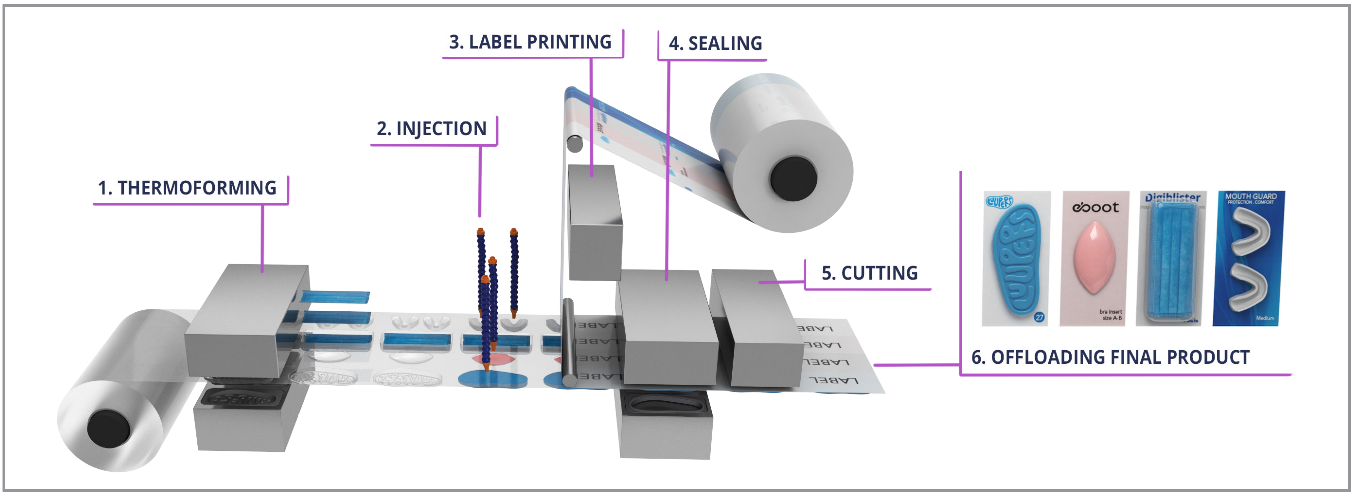
As for vertical industries adopting AM, the kingdom first saw **consumer-oriented companies emerging in the field** – which was probably due to Kyttanen's ideas on the way applications can be transformed. However, the recent years have also seen an increasing focus on construction 3D printing – which we will explore in another issue of 3D ADEPT Mag.

"Today, there is a tangible growth in every sector but digital connectivity tends to transform the manufacturing map. Let's take the example of 3D Hubs, the online manufacturing service is based in the Netherlands but the company operates at a global scale. And the need for digital connectivity has been expedited with Covid-19. We are now evolving in a manufacturing industry where companies are going to reduce their expenses, some of them will no longer need their corporate offices as they refocus their activities on the digital. Within this digital world, Netherlands-based companies will not necessarily focus their activities within the country – unless it is part of their strategic roadmap", **Kyttanen outlines**.

Another manufacturing perspective

Despite the maturity of today's market, there is still a long road to go to secure the place of AM within professionals' mind. Indeed, even though conventional manufacturing processes remain the most used technologies, a number of professionals increasingly sees a combination of both additive and subtractive processes as the best of both worlds.

As was the case 20 years ago, Kyttanen is also one of the professionals that are paving the way to a new form of manufacturing today. This time, it is 3D thermoform injection (3DTI).). The autonomous 3D manufacturing technology combines injection molding, packaging technology, laser cutting, and 3D printing.



"Within the 3DTI process, the mold and packaging are essentially the same, radically changing the way we look at products and how they are created. Molds are now just 100-micron thermoformed pockets rather than steel", the expert explains.

"My passion has always been creating the most value through digitization. With our 'What the Future Venture Capital' (WTFVC) accelerator, which we started in 2016, our focus was to invest in early startups in the 3D field. However since 3DTI has such an immense potential in the world of manufacturing, we have decided to solely focus our efforts in this technologoy platform" , he stresses.

Legend: luupers. Image via Janne Kyttanen.

In Kyttanen's view, despite the well-known and undisputable benefits of AM, the technology remains more expensive than the existing conventional manufacturing processes. That is the Holy Grail for manufacturers attempting to adopt the technology and it remains one of the reasons the industry is not experiencing fast growth. Furthermore, the manufacturing of a single part does not only require the input of several departments including finances, production, certification, and quality assurance, it also requires taking into account new manufacturing issues such as sustainability. But those departments do not often talk to each other. In the end, , *"no matter what benefits you might be able to give to a company as a whole, if the corporation is structured into silos that only focus on their own narrow P/L, the technology will not get adapted"*, Kyttanen points out.

*"**3DTI** aims to address these pitfalls. **With 3DTI we don't just deliver custom, local, and sustainable products, but higher velocity and cheaper costs than China",*** the industrial designer concludes.

The international company's perspective

As far as players are concerned, the kingdom is mostly known for its wide range of distributors. While there is an exhaustive list of manufacturers and materials' producers that are making the country's pride, the Netherlands remain a country of choice for a select number of some international companies that have decided to establish over there their European Headquarters. We reached out to **XYZprinting**'s Managing Director **Fernando Hernandez** to have their point of view on the reasons that led to their choice for this country:

Why did you choose the Netherlands to establish your HQ in The NL?

*Many reasons explain the choice for the Netherlands. The first one that comes to my mind is the **ideal geographical location**. With Rotterdam port being one of the most important ports of entry of goods into the EU, you have a max of 3-4 days travel max for the merchandise to reach any point in the EU, most of the distribution centres are in Dutch (NL) for this reason.*

*From **an economical point of view**, The Netherlands is not a paradise but it has a decent tax system and fairly decent infrastructure to support your business.*

*Regarding **human resources**, the country has a mixed population of citizens from many regions of the world especially other European countries. Thanks to the warmth of inhabitants, this enhances the possibility to have a team with mixed nationalities to do business with most countries in Europe.*

*As far as the **local environment** is concerned, the country has a very good ecosystem for AM, due to the excellent chemical background in plastics but also in terms of R&D, where Technical Universities offer excellent and skilled students with deep knowledge in AM.*

Are the majority of your European activities held in the Netherlands?

In our case yes, all our activities are held in our facilities in the Netherlands, where we perform sales, marketing, customer service, finance, logistics, trainings centre, repair centre, etc. We have partners all over Europe that help us reach other regions.

What would you say about the AM market in the Netherlands compared to other countries where you hold the same activities?

Although our office is in the NL, we work with regional partners in each region of Europe. Therefore, we adopt a similar partner strategy in each region. That being said, we perceive that the SMEs interest and penetration of AM is fairly advance in The NL compared to other regions.

Fernando Hernandez / XYZprinting's Managing Director

However, the education sector is not so advanced or mature yet, but there are some workshops in schools and education centres, at the national level there is still work to do.

What advice would you give to other International AM companies that are looking to establish an office in the country?

*Besides that, the Netherlands has a superb location within the EU from an international perspective. The city or hub location in the country is also important. Depending on the business and supply strategy, if you target only a local market, European or global, some locations offer more advantages than others. **For R&D centers, it will be recommendable to be close to Technical Universities of course.***

*The other consideration is **talent recruitment** in the Netherlands. I believe most companies would agree with me that it is a challenge to keep the right talent in the right position. The unemployment rate is fairly low comparing to other EU countries, the pay is also decent. Not only experienced employees are difficult to recruit, but as well young graduates who already can get job offers before they leave University.*

A PLAYER TO KNOW : TU Eindhoven

We have seen so many 3D printing/ AM innovations in the Netherlands but some of the most astonished ones always involved TU/e as one of the partners. We sat down with **Joris Remmers** and **Patrick Anderson** to discuss some of the current AM projects at the university. Anderson is Professor and chair of Polymer Technology and Remmers is associate professor of Composite Materials with the research group Mechanics of Materials. Both work at the department of Mechanical Engineering.

Founded in 1956 by industry, local government and academia, Eindhoven University of Technology aka TU/e is a research university specializing in engineering science & technology. However, it is in 2016 that the university takes its first steps in the AM industry by co-founding with TNO a European top center for 3D Printing.

With the goal of establishing a **center for research and development** at European level, the center first focused on the production equipment for smart, personalized and multi-functional products as well as the establishment of a TU/e chair and research group. First AM activities at the university have been observed the **Department of the Built Environment** when a research team that studied concrete 3D printing unveiled their first series of 3D printed structures achieved with their concrete 3D printer. On this occasion, the researchers 3D printed a pavilion of 2m in height to show the type of freedom in form that can be accomplished with the 3D printer.

Today, the university has explored a wide range of other AM projects especially in the materials side of the industry. "*We increasingly saw the need for industries and other organizations to improve AM processes. A careful analysis of these needs shows the wide range of challenges that needed to be met at the level of materials to allow for a perfect combination between materials and processes. In the end, the market can only bets advance if those who work on the development of 3D printing processes work in collaboration with those who focus on materials*", Anderson outlines.

At present, although there is not a dedicated training to AM at TU/e, both professors explain that the learning curve for AM is growing fast thanks to the PhD projects the university supports. The projects can be totally or partly funded by TU/e or other institutions and usually involved the input of other partners (either research institutes such as TNO or industrial partners.)

Joris Remmers
Associate professor of Composite Materials at TU/e

Speaking of the projects they are currently working on in the Polymer Technology Group, Remmers explains they are working on the deposition of fluid materials and "Discrete Element Simulation of 3D Printing Processes". The latter is part of the MultiMaterial 3D project funded by the Brabant Development Agency (Brabantse Ontwikkelings Maatschappij).

"The project aims to predict and analyse AM processes by means of discrete element simulations. It focusses on powder printing processes in which powder particles are represented by spheres. Forces and heat are transferred between particles to simulate the complex system. As a result the entire printing process and printed product can be analysed, for example by shape, thermal history or residual stresses", Remmers explains.

On the other hand, Anderson points out a few projects in **applied and fundamental research of additive manufacturing processes for polymers and food.**

As far as food is concerned, there is a **growing focus on personalized nutrition within the Netherlands.** TU/e is currently a partner of the Digital Food Processing Initiative that focuses on sustainability, personalised food, on-demand food production, new forms and flavours, and new social experiences. The ultimate goal of this project is to develop a global consortium for digitally controlled food production.

"Within our sintering projects we study why defects happen during printing and how process conditions and particle properties effects layer adhesion, porosity and mechanical properties", he explains. The project currently explains some of the current challenges professionals are trying to address. Indeed, with PA12 and PA11 as the most used powders, operators recognize that "there is often a problem with porosity or delamination when using the SLS process. That's why during testing, we often find out that mechanical properties are not as good as when the part is manufactured with injection moulding. The cause of this issue is that these materials are not often especially developed for AM."

The Polymer Technology Group's research aims at giving guidance that will therefore improve the SLS 3D printing process. So far, results show that there is a need to implement a unique experimental setup for in-situ time resolved experiments. Powders' characterization helps interpret sintering rate, material properties and processing determine final properties while one can enhance fundamental understanding of laser sintering process with modelling.

Although he cannot share further comments on this project, the expert strongly believes that what will truly drive the AM market is the ability to extend the materials we are able to print with.

Patrick Anderson
Professor and chair of Polymer Technology at TU/e

In just four years of activities within the AM industry, TU/e has explored a wide range of areas of the AM industry and the ongoing projects they are currently working on, show the crucial role of an academic perspective to advance the AM industry.

5 Key facts to keep in mind about business in the Netherlands

- Strategic geographical location

- The EU Innovation Scoreboard 2020 ranked the Netherlands as the fourth best nation for innovators.

- According to "Invest in Holland", 90% of the Dutch population is fluent in English and a higher percentage speaks German and French than their counterparts elsewhere.

GUEST COLUMN

Technology integration in AM: gaining efficiency and competitiveness

Words of Elvira LEON

Over the last ten years, additive manufacturing industry has evolved from prototyping to final parts production, where complexity and quality requirements are much higher. On the other hand, the industrial sector is evolving from low-cost mass production to more personalized production.

Mass production with additive manufacturing is one of the most important challenges for its full industria-lization. According to the report «Challenges in the industria-lization of additive manufacturing», published under the AM-Motion project (Horizon 2020 Program, European Commission), some of the challenges that additive manufacturing technology will be facing in the coming years are the **integration and automation** of production systems, and the increase in **productivity** and efficiency to gain **competitiveness** against traditional manufacturing technologies.

Needless to say, additive manufacturing enables to manufacture on demand while reducing logistics costs and environmental footprint, and achieving relevant savings with the reduction of stocks and physical warehouses. However, one of its greatest advantages will result of the integration and automation of processes: integrating equipment and software and integrating physical processes and digital thread will be crucial to make the manufacture of parts in a distributed and remote way possible, guaranteeing this way their quality and traceability.

Integrating IT/OT

Additive manufacturing is the paradigm of digital manufacturing. From a 3D file, a full object can be constructed by depositing layer upon layer of material. In this process, at some point, the digital world of a file becomes physical through an object. Therefore, digital and physical worlds need to integrate in the process.

From a practical point of view, the full integration of enterprise systems (IT) and operational systems in the shopfloor (OT) requires the fulfilment of basic steps to achieve an efficient workflow. Automation and smart planning tools are key in this process.

· Construction of a digital inventory, collecting all necessary information and digital files at every stage of the process: specifications, requirements, workflow, manufacturing & postprocessing conditions, certification needs, etc.

· Generation of customized workflow for each part, with full traceability at digital and physical stages, implementing track & trace solutions in the shopfloor, by means of QR/RFID or other suitable devices.

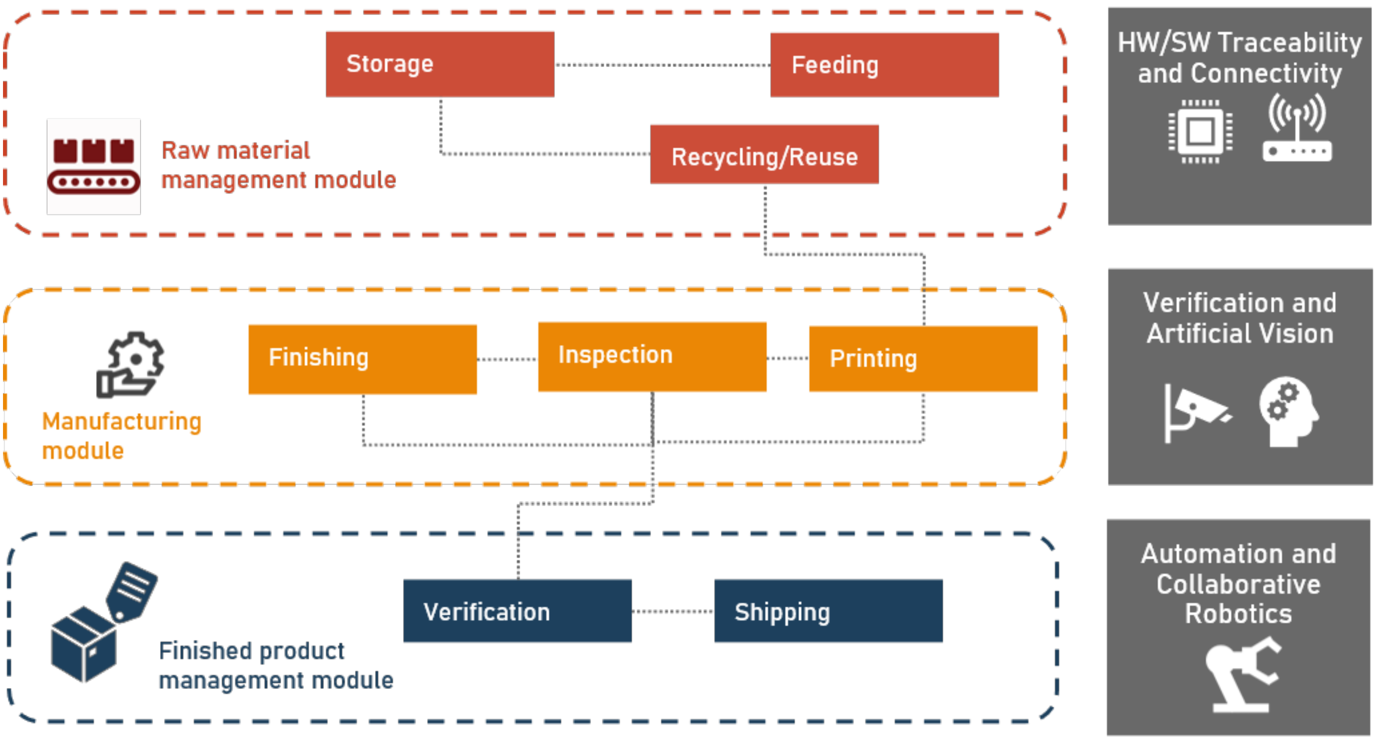
· Implement intelligent prioritization of manufacturing orders based on time of need, complete process and machine occupancy to maximize productivity (and therefore ROI).

· Guarantee full access to real-time production information.

· Implement intelligent scheduling estimation and automatic replanning against any requirements update, incidents, nonconformities, or changes in demand.

Integrating processes

This workflow in additive manufacturing translates into the integration of several different processes and operations; starting from raw material management, which must ensure compliance with storage and transport conditions, and provide traceability in storage, during feed process and after recycling. The integration of manufacturing processes (feeding, 3D printing, extraction, inspection, finishing…) opens up opportunities to incorporate automation solutions in these processes, to optimize production times and gain in competitiveness. The incorporation of automation between processes or the development of hybrid and continuous manufacturing systems is gaining traction. In any case, it is crucial to have an adequate traceability system.



Connectivity with equipment is necessary to perform a real integration of the physical and digital manufacturing flow and allows real-time process monitoring and validation of manufacturing parameters. Traceability and integration of production systems must be maintained until the finished product management stage. The integration with ERP (Enterprise Resources Planning) system and with MES (Manufacturing Execution System) ensures full process traceability from raw material to shipment, saving time and resources in inspection and documental management tasks.

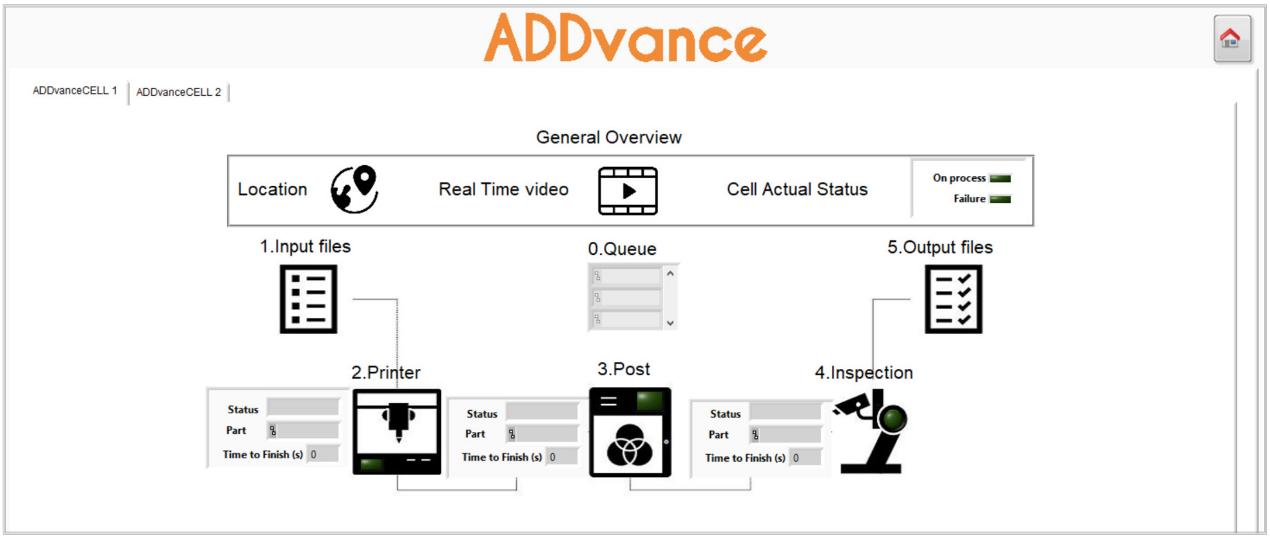
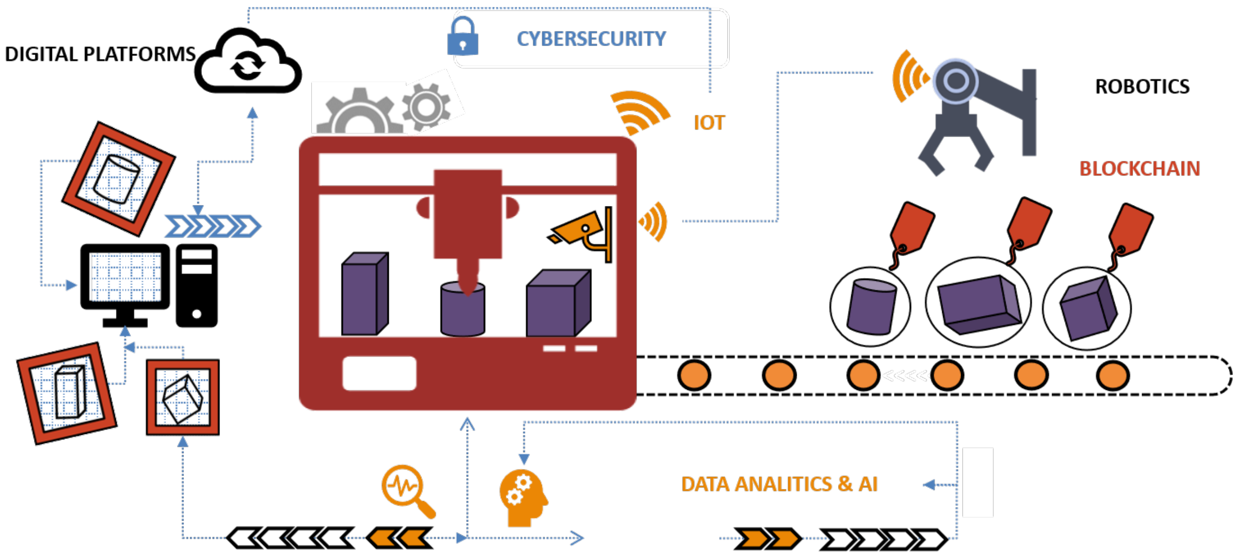


Figure 1. Image of Production module of ADDvance Platform, with connectivity with equipment and real time process information

Integrating Digital technologies in AM

Some of the challenges in additive manufacturing to gain competitiveness over other conventional manufacturing technologies are reproducibility and productivity. In both cases, the advances and improvements in new systems are huge, with the integration of different digital technologies such as Data Analytics and Machine Learning for process monitoring, Robotics solutions for automation or IOT (Internet of things) and Digital Platforms to connect equipment, devices and IT systems.



Influence of the manufacturing process

Additive manufacturing is a manufacturing process considered to be 'special', like welding, adhesive or manufacturing of composite materials. This means that the effect of variability of the numerous parameters of the manufacturing process can substantially influence the result. Therefore, it is very important to define these parameters and their range of variations and monitor them during the process. For the first step, when it comes to parameters in low-cost technologies, you can either rely on experience or some tests. For high-cost technologies, the trial-and-error technique can be too costly, hence the use of **process simulation techniques.**

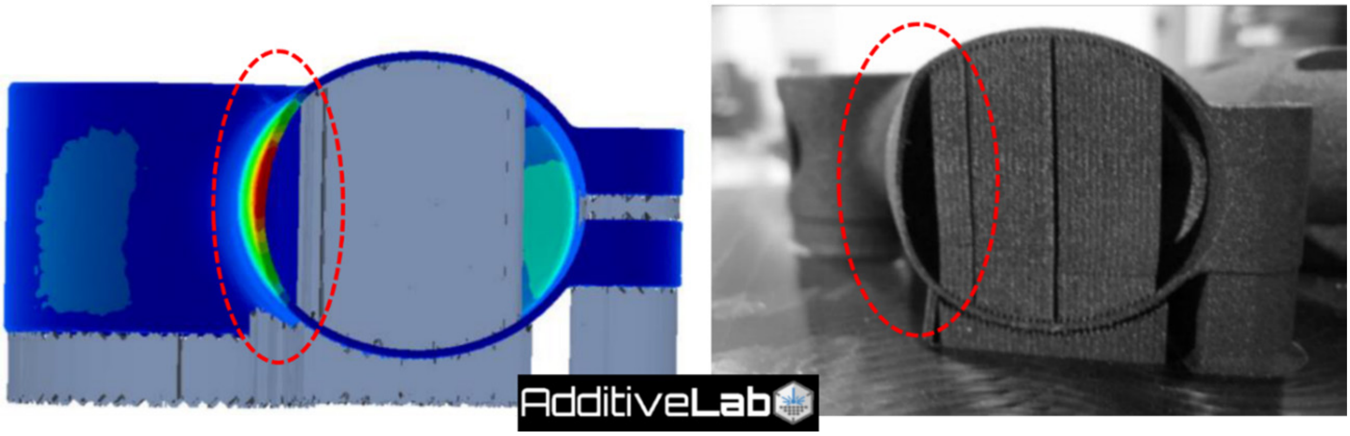


Figure 2. Comparison of deformation prediction by simulation and the result in the manufactured part. A change in the chamber manufacturing position, or in process parameters could have prevented the manufacture of a non-compliant part, resulting in cost savings.

Regarding process monitoring and control, data analysis techniques using Machine Learning and Deep Learning are being used to identify potential deviations by analyzing interaction between different parameters, which would be impossible to detect with simpler monitoring techniques. On the other hand, advances in this area also include the development of predictive (warning of deviation before it occurs) and even prescriptive (establishing action to counteract the identified deviation) models.

Information flow and security

Because of the inherent nature of digital manufacturing to additive manufacturing, **security of digital thread is a critical factor**. Huge progress is being made in this area to ensure that there is no variation or attack on data throughout the process **(system security protection)**, and to ensure that access to data is done in a controlled and authoritative way **(intellectual property protection).** These two factors are critical and essential to enable a distributed manufacturing business model.

System security **(Cybersecurity)** involves protecting the hardware, software, and firmware of computers (IoT and OT systems).

For the protection of intellectual property, **Blockchain** technology is used to track and trace the flow of information, and assess that objects are produced in a previously validated equipment, that the number of units manufactured is the one stipulated and that it is done by authorized manufacturers.

ADDvance provides services and products to support an efficient industrialization of additive manufacturing. ADDvance supports their customers to build their own digital parts inventory and enable distributed and remote manufacturing, ensuring the quality and traceability indispensable in those parts by using ADDvance platform.

ADDvance also commercializes fully autonomous production cells (ADDvanCELL®) enabling in-field manufacturing and remote management. ADDvanCELL® production cells integrate all the equipment and software necessary for printing, finishing and verifying, and provide the platform to manage production autonomously and remotely, with total traceability and security. ADDvanCELL® solutions can integrate robotics and artificial vision in those applications in which human interaction needs to be minimized.

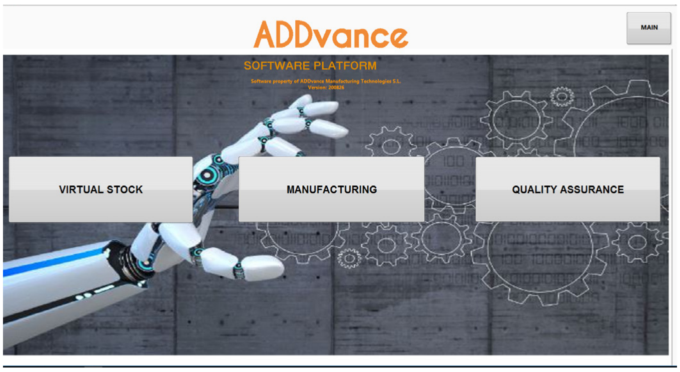
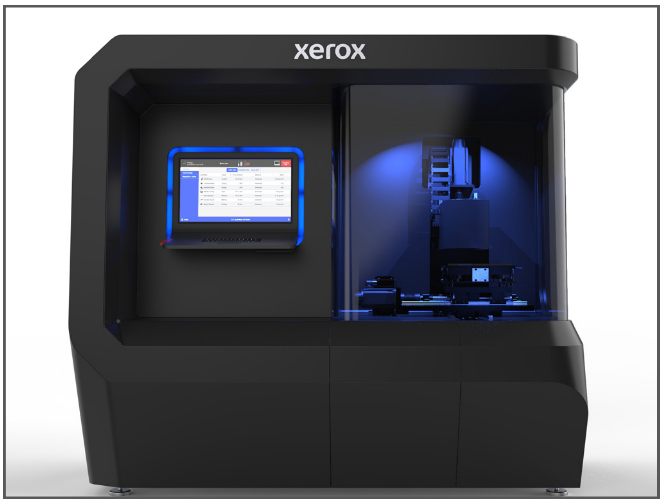


Figure 3. Dashboard of ADDvance Platform, showing the Digital Inventory, Production and Certification modules

NEWS ROUND UP

This news round-up highlights the latest 3D printers that have been unveiled during the months of January & February. Scan the barcode or click on the title to read the full article on www.3dadept.com.



[A lot is happening at Xerox: Organization changes, First Metal 3D Printer Installation and Collaboration]()

Ever since it has debuted on Formnext 2019, Xerox has remained in stealth mode – until today.

SCAN ME

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Creating a more stable thermal environment during the printing process.

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[ExOne and Rapidia reveal an Office-Safe Metal 3D Printer that enables true "Print Today, Parts Tomorrow™" innovation]()

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Meet the Stratasys J850™ Pro 3D printer, a Multi-Material Polyjet 3D Printer without full color

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Desktop Metal's Studio System 2 achieves Metal 3D Printing in just 2 Steps: Print and Sinter

Look at the Hammer Lab35 Metal 3D Printer now because Incus to scale up series production

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atum3D's new DLP 3D Printer and vacuum post-curing fit the needs of orthotics and orthopaedics

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