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# 3D ADEPT MAG

## 3D PRINTING

**INTERVIEW : HYPERGANIC**

**DOSSIER : UNVEILING THE DISGUISED COMPLEXITIES OF WIRE-ARC AM**

N°3 - Vol 4 / May - June 2021

Edited by 3D ADEPT MEDIA - ISSN : 2736-6634


ISSN : 2736-6634

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3D ADEPT MEDIA
All about Additive Manufacturing

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# Hello & Welcome

## Summer is around the corner...

Summer is almost here. For the first time in a year and a few months, these words are not meant to encourage, nor to talk about the warm weather - although they literally refer to that. These words allude to our industry which is slowly but surely returning to a certain normality as trade shows slowly open once more.

I cannot count the number of people who told me how much they miss trade shows, meeting days at their facility, or team building activities...Well, this was also the case for our 3D ADEPT Media team which hasn't seen a lot of companies, collaborators, new or old players in the industry for a while.

In addition to those who receive the print version of the magazine at home, the 5th Military Additive Manufacturing Summit that is being held in the USA, will be receiving and distributing this May/June issue to all their attendees as well.

This issue is specifically interesting for military uses as we have extensively covered the topic of wire-arc additive manufacturing in our «dossier». A dossier reminding us that WAAM may be one of the oldest processes to exist – with the first patent being delivered in the 1920s - but it remains the least highlighted in the range of AM processes, and obviously, there is a reason for this.

Furthermore, with technical progress, new elements are increasingly facilitating and accelerating processes, allowing these technologies to become more accessible or popular. This can be seen in the sections on software and this month's interview on the one hand, and materials and applications in the sports sector on the other hand.

There is much more to read for sure, but I'd rather let you discover it for yourself.

Yours sincerely,

**Kety SINDZE**
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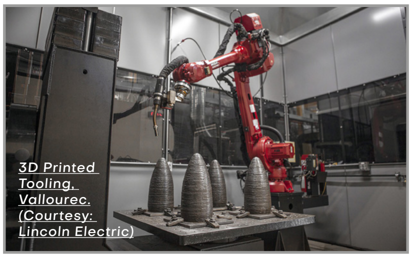
Editorial

# UNVEILING THE DISGUISED COMPLEXITIES OF WIRE-ARC AM



3D Printed Tooling, Vallourec. (Courtesy: Lincoln Electric)

*With a first patent granted in the 1920s, Wire-Arc Additive Manufacturing, short for WAAM, is certainly one of the oldest AM processes that exist, yet the technology is the least highlighted in the range of recognized AM processes. The reason for this slow adoption at the industrial level may lie in the gap that still needs to be fulfilled in the supply-chain.*

Driven by the demand for increased manufacturing efficiency of engineering structures, WAAM which is also known as **directed energy deposition-arc** (DED-arc), can basically be seen as the integration of an "additive" principle in the wire-arc welding process. According to manufacturers, given the fact that in a welding process, heat energy is used to fuse the molten metallic pools one upon another, the transformation of the process into an additive one was quite understandable. From a technological standpoint, the additive process can deliver high deposition rate of the metallic feedstock in the form of a wire filament, the same as with the conventional welding process. This might explain why first manufacturers of WAAM systems have a strong expertise in the welding industry.

According to **Wim Verlinde**, Welding Consultant & Engineer at **the Belgian Welding Institute (BWI)**, other reasons & questions may explain this influence of WAAM in the welding industry:

*"There are still a limited number of conventional processes for the manufacturing of big parts. Castings are one of these processes but they still require a number of developments such as moulds; and it becomes challenging to make big parts for small series, which in the end might be extremely costly. Another reason is that WAAM can serve a lot of other applications such as repair parts achieved by Guaranteed, spare parts on demand, prototyping, etc."*

Two years ago for instance, the BWI team started a research project (funded by VLAIO – Agentschap Innoveren en Ondernemen – Vlaanderen) when realizing that a lot of robots were shipped to their facilities and remained unused during night or weekend. Verlinde explained that their team came to ask themselves, if they could turn a normal traditional welding robot into a 3D printing robot.

According to the welding consultant, the disruptive impact of WAAM on the welding industry may lie in the fact that the process requires a specific material in different locations of the 3D printed part to achieve for instance fatigue, corrosion, or high stresses. In these cases, the part is built in specific areas with specific materials, or the manufacturing process may require the use of two wires that are mixed in-situ and composed together to achieve a specific goal. (According to the expert, such production scenarios are quite complex as they may lead to some metallurgical issues).

Although it is acknowledged for the large-scale manufacturing industry, WAAM does come with a number of constraints at the manufacturing level. The present dossier aims to:

- Help professionals understand how the WAAM process works;
- Shed light on the different challenges engineers often encounter when manufacturing with WAAM and shed light on the potential solutions that could be used to overcome them. This includes revealing the gap in the supply chain we mentioned above;
- Share some examples of applications & a few WAAM-dedicated solutions available on the market.


Legend: Repair of a hot wind body performed by Guaranteed. So far, already two of these components have been refurbished allowing the customer to save 90% on the original part purchasing costs. Courtesy of Guaranteed.

## WAAM: processes & capabilities

Simply put, in a WAAM process, an electric arc is used as a primary source of the heat to achieve near net shape preforms without the need for complex tooling, moulds or dies. Just like there are several types of metal AM processes, one can identify various sub-categories of WAAM processes.

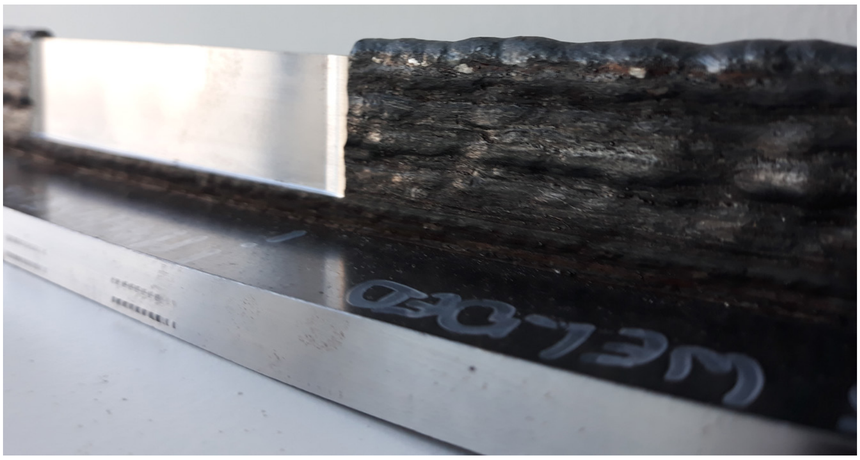
According to **Mark Douglass**, Business Development Manager at [Lincoln Electric Additive Solutions], those sub-categories are based on the different arc welding processes:

*– "Gas metal arc welding (GMAW) or as is often categorized in Europe "MIG/MAG"; this is the process most often referred to and the one Lincoln employs;*

*– Plasma arc welding (PAW), which is the one Cranfield University popularized; Gas tungsten arc welding (GTAW) [also known as Tungsten Inert Gas (TIG) welding]".*

However, as far as the **equipment** itself is concerned, WAAM systems' developments vary from one manufacturer to another (as we will see at the end of this dossier) but most of the machines fall into either **robotic** or **machine tool-based**.

*"Some manufacturers start from a CNC machine and turn a CNC machine into a weld printer, and then, they do the machining and the printing within the single platform. Machine manufacturer GEFERTEC for instance, develops its AM machines based on this principle"*, Verlinde notes. Furthermore, as he explained earlier, it is possible to combine any three-axis manipulator with a six-axis robot arm and an arc welding power source to develop a basic WAAM system. The robot can be combined with a grinding robot (in one platform) or with a traditional CNC for surface finishing.



Caption: surface condition as WAAM printed versus CNC machined. Courtesy of Belgian Welding Institute.

| | **WAAM robot** | | **WAAM CNC machine** |
|---|---|---|---|
| | **+traditional CNC machining** | **+ robot grinding-polishing** | **+traditional CNC machining** |
| Versatility (to be used for other tasks then WAAM) | ✓ WAAM<br>✓ machining<br>✓ traditional welding | ✓ WAAM<br>✓ grinding<br>✓ traditional welding | ✓ WAAM<br>✓ machining<br>✗ traditional welding |
| Large scale components | (robot on rail) ✓ | (robot on rail) ✓ | Volume[1] : 0,06m$^3$ -3m$^3$ ✓ |
| Number of AXES | Robot: 6 axes<br>Manipulator: 3 axes<br>Rail: 1 axe | Robot: 6 axes<br>Manipulator: 3 axes<br>Rail: 1 axe | 3 or 5 axes |
| One-step production | ✗ | ✓ | ✓ |
| Intermediate machining during WAAM printing (in function of accessibility) | ✗ | ✓ | ✓ |
| High precision machining | ✓ | ✗ | ✓ |

**Table 1: Advantages and disadvantages of different WAAM printing system**

No matter how they are built, these machines should be backed by strong CAD/CAM software.

### *The software perspective*

The fabrication process with WAAM starts with a CAM software that helps to generate the toolpath and the welding parameters for the gantry table; then one can control the start/stop points of welding and determine the feed rate of metallic wire filament. As seen in any additive process, the software should be capable to convert the CAD model to a printable code by following the slicing principle. Once the process has started, the welding torch moves in a given direction on the build plate and triggers the wire feeder to deposit the material in the path.

Software tools and systems play an important role in the process preparation. Nowadays, it is possible to divide the existing software for WAAM in two main categories: **stand-alone** applications and **plug-ins** that are integrated within existing CAD/CAM software.

Plug-ins for WAAM are developed and integrated in a number of CAD/CAM software tools. The main advantage is the possibility to prepare both WAAM and machining steps within a single software platform. The functionality, compared to stand-alone applications, is sometimes limited: mainly in the variety of deposition path strategies, control and setting of the welding parameters, etc…

| Plug-ins (= based on CNC CAM) | Stand-alone (= WAAM specific) |
|---|---|
| · Sprutcam robot<br>· PowerMill (Autodesk)<br>· Robotmaster<br>· Hypermill (Dassault Sytems)<br>· Siemens NX<br>· Eureka | · Metal XL (MX3D)<br>· Factory OS (OQTON)<br>· WAAMMat (Cranfield University) |

***Table 2: Overview of available CAM software solutions for WAAM printing***

*The Belgian Welding Institute (BWI), VIVES and KULeuven are independent research institutes. Any supplier of CAM WAAM software can be added to this table.*

When making a choice, the following software features must be evaluated depending on the application, complexity, shape, etc.:

| | CNC based | Specific WAAM |
|---|---|---|
| **Toolpath** | CNC based, but improvements going on | Dedicated for WAAM |
| **Slicing needs depending on shape and complexity** | · planar<br>· none-planar (cylindrical – spiral)<br>· variate the distances/height between the toolpath<br>· medial axis (contour in-wards or out-wards) | |
| **Inclined wall** | · number of external axes that can be controlled 1 or 2<br>· software adjustment (experiments) | |
| **Self-adjusting (compensation layer height, width)** | More difficult | · (intermediate) scanning can be integrated<br>· Possibility: artificial intelligence<br>· Calibration mode by experiments and adjustment of parameters |
| **Software** | Desktop software | Desktop software or cloud based |
| **Single width wall** | Yes | |
| **Multi width wall** | Yes | |
| **Padding (extra thickness to compensate machining)** | To be done in CAD software | · To be done in CAD software<br>· In some software: easily xx mm can be added. |
| **Graphical User Interface** | Interface is CNC based so no WAAM vocabulary: (too) many parameters | Clear and simpler because WAAM dedicated |
| **Data capturing** | Possible, but not integrated (stand-alone) | Yes (interpass temperature, current, voltage) and related to the location in the part |
| **Welding parameters** | · Splitting up the part and a separate file with 1 welding parameter set (not complex parts)<br>· Not splitting up the part but "intermediate" scanning, comparing to 3D model and adding extra layer (artificial intelligence)<br>· Parametric set-up by calibration mode | |
| **Follow up during printing** | Difficult (only webcam for example) | Visualization and errors |
| **Post processing** | Most robot brands are possible, but welding unit has to be done as well | More limited choice to specific brands |
| **Import of 3D model - file format** | Most of the 3D formats | Most of the 3D formats or sometimes limited to one (f. ex STL) |

***Table 3: Plug-in software (= based on CNC CAM) versus Stand-alone (= WAAM specific)***

For **Verlinde**, "***the design engineer has a major task here***. *Unlike other industries like steel constructions or pressure vessels where everything is ruled by (harmonized) standards for the design engineer, here, the design engineer has to decide what the materials' characteristics are, what potential defects may occur, what kind of finishing is required – since the finishing depends on the application. Unfortunately, he is still limited in his work by standards. For some applications for instance, which have stringent regulations, he does not have the freedom to decide how he will build the part.*" The design engineer might require a skilled multi-disciplinary team to decide on all of the topics depending on the complexity and the risks of the part.

In other terms, designing for WAAM means pinpointing all workpiece geometries that are most suitable for the final real-world applications. In the aerospace industry for instance, new lightweight stiffeners are used to meet specific mechanical constraints.

In the same vein, since the WAAM process delivers high deposition rates, the design engineer should take into account the fact that the large heat input of these processes may also lead to significant residual stresses and distortions.

In such cases, *"pre-heating may be used to control distortion. It is possible to model distortion and compensate in the tool path based on the prediction, however I do not believe effective tools have been developed yet. Otherwise experience can help greatly in managing distortion"*, **Douglass** observes.

The fact is that these issues can badly impact the accuracy of the final shape of the parts and their mechanical performance. Therefore, it is important to take the thermo-mechanical behaviour of the WAAM process into consideration during the design stage.

### *The materials perspective*

For each type of power source available, the material in use can drive the given arc deposition process. For instance, titanium alloys are widely processed with **gas tungsten arc welding or plasma transferred arc** while most materials are deposited with MIG/MAG equipment.

*In a general, all materials available as a welding wire be used for the production of parts via WAAM although, "certain precautions such as pre-heat may still be necessary"*, according to Douglass.

While he agrees with this generalisation, Verlinde nevertheless nuances his answer:

*"Most materials are suitable for printing because we weld them but it all depends on what you expect in the end on material characteristics and weld imperfections. Some materials like aluminium and titanium are more challenging and used in critical high-end applications but they enable shorter production time. The problem of most companies on the market, is that they think that WAAM is already at the same place that powder-bed fusion but this is not yet the case. However, it is clear that on many levels (software, machining, research …) great progress has been made since we have started the project".*

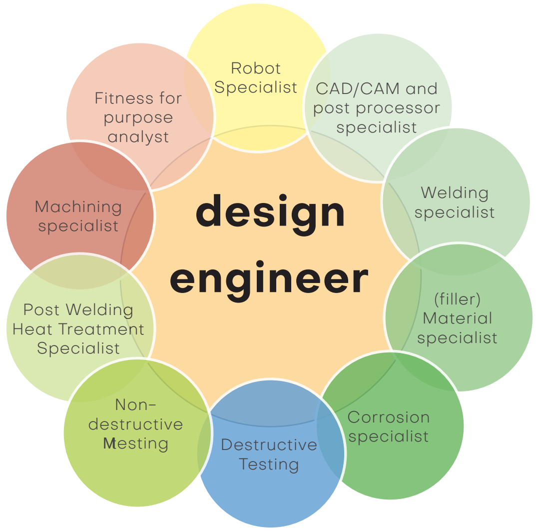



Figure: Multi-disciplinary Team

On the other hand, **gas tungsten arc welding** can process a wide range of materials including carbon and low alloy steels, stainless steel, nickel-based alloys, titanium alloys and aluminium alloys.

**Douglass** also raised our attention on the fact that comparisons between 3D printed parts produced via WAAM and parts produced with cast or wrought material are not straightforward *"as alloys developed for welding wire are often not the same as those for castings and wrought."*

Mark Douglass, PhD, CFA – Business Development Manager, Additive Solutions

*"Therefore, one needs to match desired deposited material properties with available wires. That is, while wire chemistry may not match a given wrought or cast chemistry it is often possible to achieve, and even surpass, the desired mechanical properties.*

*[On the other hand,] WAAM deposited metal can be of very high quality—as good as wrought and often better than castings, for example in many cases WAAM has significantly less porosity than castings. Welding has been used to reliably join very critical components and even repair critical castings for many decades, which provides great confidence to end users that very high internal quality is achievable"*, he adds.

Nonetheless, one thing most manufacturers agree on, is the fact that WAAM is acknowledged as a process that enables to achieve material consumption. Needless to say, the percentage of reduction may vary from one application to another but may rise up to 70% in certain applications, as compared to conventional manufacturing processes.

Caption: Lay-up mold for aerospace composite part manufacturing; material: Invar; approximately 200kg and over 3m in length – Courtesy: Lincoln Electric

Douglass recalls here, that for an application achieved for a mining equipment customer, they've had weight and material savings of **over 20% for component** that was about a meter long and **almost 200 kg**.

## The post-processing perspective

Like in every AM method, most applications will require a specific range of post-processing tasks to achieve the desired manufacturing goals. In this directed energy deposition-arc process, the expert from Lincoln Electric Additive Solutions points out that this manufacturing process may require to use the same post-processing tasks used for any casting or fabricated component: "*heat treating (for stress relief and/or mechanical property enhancement), machining, additional fabrication or joining to other components*". Nevertheless, "*WAAM components are fully dense, therefore t**here is no need for hot isostatic pressing (HIP)***", he clarifies.

## Advantages, areas for improvement and future outlooks

This dossier can only present a general overview of the WAAM process. Based on our exchanges with the two experts who have been invited to share their insights into this topic, we can summarize the following advantages and challenges that still need to be overcome by manufacturers:

| Advantages | Areas for improvement |
|---|---|
| Ideal for manufacturing (very) large parts | Long lead times for castings and forgings of new parts, tooling or prototypes. |
| High deposition rate and high mechanical strength of the parts | Residual stresses and distortions – (A better control of these issues comes with experience on the manufacturing floor) |
| Lighter weight parts and less waste. | Shielding for some materials |
| Faster prototype testing. | Most responsibilities fall down on the design engineer and this is certainly due to the lack of standardization in the field |
| Reduction in lead times from months to weeks. | Product testing and industry regulations that may lead to some delay and/or extra time for redesign or re-manufacturing |
| Processes tend to be more automated | Machining – surface finishing (CNC or griding) |

Since its first patent granted in the 1920s, one should recognize the fact that the WAAM process has quite evolved. In 1983, shape welding was used to manufacture large nuclear steel parts. A decade later, ***Prinz and Weiss*** patented «Shape Deposition Manufacturing» with CNC milling. At the end of the 20th century, **Cranfield University** was granted a patent for the Shaped Metal Deposition process for developing engine casings using different materials.

We can envision a fast adoption of WAAM with the appropriate resources brought by key stakeholders in the supply chain; resources that include the appropriate software tools, improved hardware, raw materials, training and services but also, machining and most importantly, standardization.

Today, experts in the field continue to push the boundaries of this metal AM process. White papers or books have been developed by companies and made available to professionals who would like to further explore this process. Several researches continue to be undertaken to investigate its benefits, in situ alloying for instance, along with methods that employ wire to create new composites.

We strongly believe that the best way to objectively assess the capabilities of WAAM as a viable metal AM process should be to do so by avoiding the comparison with other metal AM processes. WAAM is WAAM and will never be powder-bed fusion, nor binder jetting or anything else. In the end, each of these metal AM technologies has its pros and cons, and WAAM is worth considering as the more the market evolves, the more manufacturers are developing new WAAM-designed hardware and services, leading to even more success stories in the field.

**Examples of applications and a few WAAM-dedicated solutions**

For a technology that is said to hold a huge potential for large-scale AM applications across multiple industries, we were keen to discover how large a part can be. To this question, **Douglass** answers, *"in theory there is not a limit, though realistically there is eventually a practical limit with robotic or gantry systems."*

Applications of WAAM may be explored in the **aerospace, automotive, oil & gas, energy and other heavy industries**.

In the current market, the list of companies and organizations that have been developing WAAM-dedicated solutions is relatively exhaustive. They include for instance: **Lincoln Electric Additive Solutions, Gefertec, MX3D, Ramlab, Guaranteed, OQTON, AML3D, WAAM3D, Addilan, KRAKEN, voestalpine Böhler Welding Automation,** and Vallourec.

Apart from these organizations, there are also research institutes that continuously explore WAAM as a manufacturing process, and develop new techniques to enhance the process. From the list of research institutes that operate on the market, we have invited the Belgian Welding Institute that supports companies that want to take steps towards WAAM additive manufacturing of metals; from mechanical/corrosion testing, first feasibility studies, and have the industrials leads to integrate the technology into your production environment. **Wim Verlinde**, an expert on this topic, told us the institute and their project partners KU Leuven and VIVES have already worked with WAAM software like MX3D, Sprutcam, OQTON, PowerMill (Autodesk) or service providers like MX3D, Guaranteed, OQTON, … on WAAM-dedicated projects. They are currently involved in some standardization projects that may enable a better adoption of the technology across industries and help designers to make decisions more easily when it comes to material characterization.

### *Lincoln Electric Additive Solutions*

Lincoln Electric Additive Solutions is the additive manufacturing division of Lincoln Electric, an American multinational and expert in the design, development and manufacture of arc welding products, automated joining, assembly and cutting systems. Thanks to its parent company's 126-year-old heritage and $500M USD automation business, Lincoln Electric Additive Solutions has developed a **robotic gas metal arc welding.**

**Mark Douglass**, Business Development Manager at **Lincoln Electric Additive Solutions** who has been invited as a key contributor to this dossier, explains how their technology works:

*"An electric current creates an arc between a wire electrode and substrate, which melts the wire and lays down weld beads which form the layers. The electric current is generated and precisely controlled by our Power Wave® power source whereby we can program advanced current waveforms to achieve optimal arc characteristics for a given alloy".*

Well-aware on the pivotal importance of the software in a WAAM process, Lincoln Electric Additive Solutions has developed a software. Named **SculptPrint™ OS**, it slices the CAD files, plans the tool path for the robot, and programs the robot.

The company has incorporated advanced coordinated motion between a 6-axis industrial robot and multi-axis positioner in order to produce more complex geometries while minimizing or even eliminating support structures. According to Douglass, their proprietary adaptive layer height and width controls ensure they are maintaining proper layer height compared to the planned model.

Lincoln Electric production WAAM systems - . (Courtesy: Lincoln Electric)

An interesting distinctive advantage may be the fact that Lincoln has control over the entire value chain of the process, since it "*manufactures its own power sources, wire feedstock, positioners, integrated robotic systems, software and controls*".

It should be noted that, although the company develops its own systems, it does not sell them for commercial production and rather acts as a manufacturing service provider.

As far as applications are concerned, the engineering team has already produced individual parts of **over 2 meters and 1,400lbs (635 kg).**

### *Focus on applications with Guaranteed*

**Guaranteed** is a spin-off company from Finindus, ArcelorMittal Belgium and OCAS. We discovered the company's expertise when they took part in a dossier exploring AM in the oil, gas and maritime industries (July-August 2020 edition of 3D ADEPT Mag). Verlinde mentioned the Belgian service provider as a company that manufactures repair parts using WAAM.

We also learned that for each application, the company's software automatically programs the robot and the welding systems while a second software package can simulate the welding process and provides certainty at the micro level. This means that further information can be provided on the dynamic properties and quality of the repaired parts.

The company explains on its website that they can process parts up to ten by six by five meters, with a maximum weight of 20 tons. They currently have a database of about 24 materials which can be increased upon request. According to **Joachim Antonissen**, Managing Director, their primarily focus is the repair market that may generate millions of savings.

One of the repair parts Antonissen shared as part of this dossier is a **mandrel bushing**. He explained that during the manufacturing process, the "original material was upgraded to achieve a higher strength after repair and thus prolong the component's lifetime. Repairing the part costed less than one third of the new part cost, while energy consumption and carbon emission were reduced by more than 90%."


*Legend: Repair of the mandrel bushing. Courtesy of Guaranteed.*

### WAAM3D Ltd, a spin-out company from Cranfield University

If you start researching insights into WAAM, you can't miss the fact the Cranfield University has been at the heart of major developments on WAAM. Following the patent the university was granted in the 20th century, researchers continue to explore the possibilities of the technology via a large collaborative programme called WAAMMat. Last year, WAAM3D Ltd., a spin-out company from Cranfield University, officially announced its first steps on the market through investment from Accuron Technologies Ltd.

"*The basics of WAAM are about melting wire with an electric arc. What we do differently is firstly having a wider choice of arc processes to draw from depending on the requirements our partners have (material, geometry, size, etc). Secondly, we have a patented method to hybridise arcs with lasers to achieve both higher deposition rates and greater control over the final geometry. Thirdly, we have another patented method to introduce cold-work into the parts, and improve resulting mechanical properties dramatically to meet the more stringent requirements applied to critical parts*", **Filomeno Martina**, CEO and co-founder of WAAM3D Ltd told 3D ADEPT Media.

Unlike other players that bring a key expertise in welding on this market, WAAM3D Ltd said its technology has been developed with WAAM in mind – not welding. Their systems integrate a set of sensors that facilitate quality assurance and control, for example in-process live measurement of shape.

Like fellow companies that specialize in the field, the start-up has also developed a dedicated software suite which comprises **WAAMPlanner** and **WAAMCtrl**.

The WAAMPlanner is made up of a CAM package in which the engineer can draw the trajectory of the printing process with embedded process parameters based on the CAD of the part. **WAAMCtrl** is described as the "brain of the process". It enables the machine supervisor to monitor the process from anywhere, whilst the part building data gets stored safely.

"*We also manufacture wires designed for WAAM, with an incredible quality in the resulting deposition. Therefore, the user experience is consistent with what you would expect from such a futuristic, amazing technology that will no doubt change manufacturing*", **Martina states**.

While the start-up can't share some images of their application due to confidentiality, Filomeno Martina said one of his favourite applications is the **titanium fuel tanks for satellites** the team achieved in partnership with Airbus Defence and Space as well as the work performed at Cranfield in partnership with BAE Systems on the massive **Eurofighter Typhoon titanium frame**.

## MX3D, from 3D printed steel bridge to a portfolio dedicated to WAAM

The whole industry discovered **MX3D** when the team unveiled the 3D printed steel bridge they built over the Amsterdam canal using **Robotic Wire Arc Additive Manufacturing**. Their journey in the industry started in 2014 in Joris Laarman Studio, a Dutch design agency working with new technologies such as 3D printing.

Over time, the company has continuously explored new applications through collaborations with other entities and has been enhancing its solutions. A recent investment round the team secured, reveals that the company has been developing the **M1, Metal AM System and MetalXL, software package, dedicated to WAAM**.

The Dutch manufacturer told us that their process is very similar to robotic welding. However, rather than placing just a few welds, components are printed by continuously stacking welds on top of each other. The solution therefore comprises three base components: an industrial robot, a welding machine and a software package (***MetalXL***) that ties it together and transforms it into a 3D metal printer.

*"These robots can print in almost any metal that is available as a welding wire and the printed objects range from football-sized up to car-sized items. Next to the MetalXL software to program the robot and welding machine to print the CAD-design into a metal object, we now also have developed and connected a MetalXL Control System to monitor, control, and log the full print process in real-time at high resolution"*, MX3D notes.

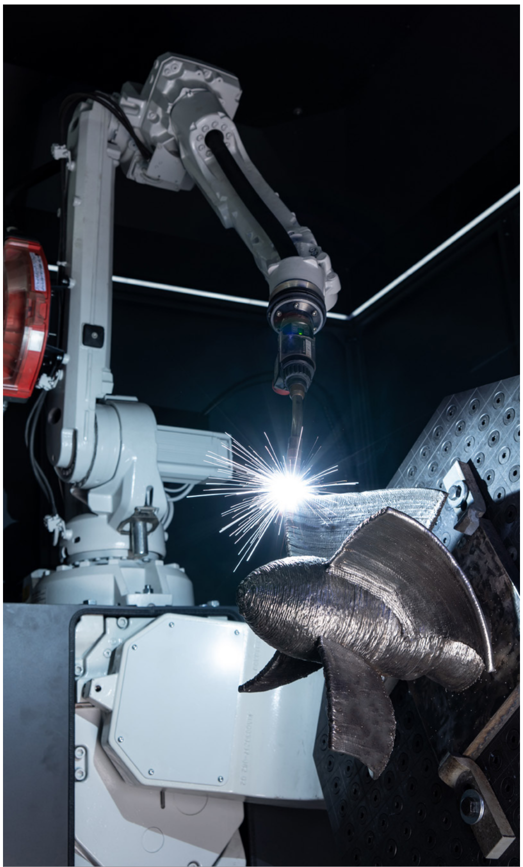
MX3D M1 Metal AM System– Courtesy of MX3D.

The MX3D team is a true example of a company that learns on the ground. As a matter of fact, their first application – the ***MX3D Bridge*** – revealed pain points such as the need for combining various hardware devices with multiple software packages, and a lot of manual coding to achieve optimal print results. The project also raises the interest of other industries in WAAM, which in the end, inspired the development of MetalXL. This solution can *"turn an existing robot and welding machine into an industrial-grade 3D metal printer within a day"*, the company states. Once users have uploaded their designs, they can choose their ideal material for production (from a material library or custom alloy), select various printing strategies and set relevant process parameters.

Apart from the MX3D bridge, we have also reported through our online media, on other applications achieved by the company. They include for instance, an **optimized robot arm**, a **high-strength structural steel connector** made in collaboration with the Japanese architectural, engineering, and construction firm Takenaka, and **two printed bicycles**.

The latest to date is a **stainless steel propellor on an 8-axis robotic system**. With a total weight of 70kg, the propeller required 24 hours of print time. It confirms one of the key reasons why manufacturers can be interested in robotic WAAM technology: reducing manufacturing lead-time, in particular for custom of small series productions.

*"The best way to apply and use additive manufacturing effectively is to start printing. We have learned by doing, trying out new ways to achieve higher quality and printing very different applications for a variety of industries. With our MetalXL technology, we now enable others to also start 3D metal printing in-house"*, the company concludes.


Caption: propeller – Courtesy of MX3D

## AML3D and its Arcemy®

Founded by **Andrew Sales** in 2014, **AML3D Limited** is an Australian manufacturer who has been developing a Wire Additive Manufacturing or WAM® technology named Arcemy®.

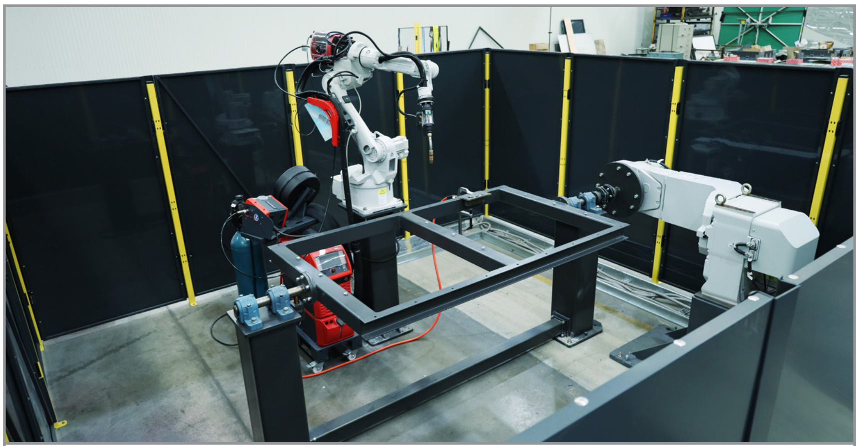
After experiencing the traditional arc welding process, the founder has been researching, developing tools and processes to enhance the Wire Additive Manufacturing process. His research led to the development of the ARCEMY® print module which is being commercialized today.

*"Born from traditional welding processes, AML3D's emerging WAM® technology is adaptable, allowing for an extensive range of capability to manufacture by means of point-to-point welding (i.e. pipe welding) through to additive metal layering (metal 3D printing) to fabricate near-net parts in a free-form environment"*, the company states.

The company's Direct Energy Deposition (DED) technology uses a variant of Wire+Arc Additive Manufacturing (WAAM). Its ARCEMY® technology combines the capabilities of welding science, robotics technology, metallurgy and the company's proprietary software **WAMSoft®** and **AMLSoft®**. **Interesting fact**, the manufacturer can remotely monitor and/or manage the ARCEMY® Print Module from the Central Control Room located in Adelaide (Australia).

Among the key features that may help the ARCEMY® system distinguish itself from others of the same range, one notes that the certified manufacturing process WAM® uses certified wire feedstock for manufacture, which is sourced locally, allowing for production to stay on-shore.

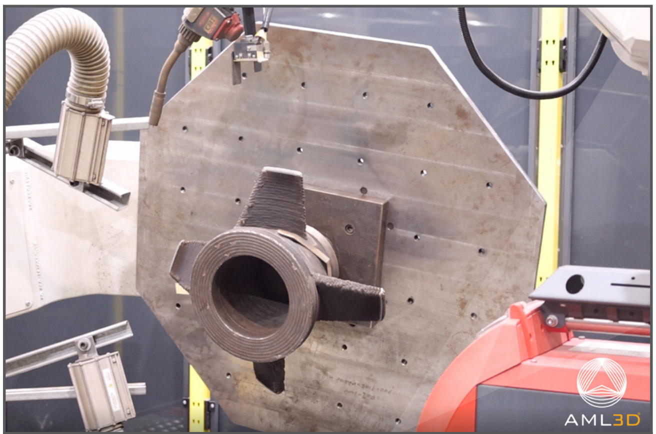
The Australian expert ensures that, due to the manufacturing process which has been supported by NATA testing, WAM® steel printed parts are stronger than forged. From a materials perspective, *"up to 80% material waste can be saved when compared to traditional subtractive manufacturing and there is also no consumable wastage, as 100% of the wire consumable is deposited for the near net part/shape being produced"*, the company told 3D ADEPT Media.



AML3D branded robot – Courtesy of AML3D.

AML3D has already achieved several applications such as an elbow pipe or a propeller. The company points out that WAM® printed parts can be printed on-demand - in a few weeks – and 3D printing maritime applications can receive official verification from DNV.

*AML3D Elbow pipe – Courtesy of AML3D.*



*Legend: propeller – Courtesy of AML3D.*

### GEFERTEC: more than just another metal AM alternative

**GEFERTEC** is one of the machine manufacturers **Verlinde** mentioned earlier when talking about machine tool-based WAAM systems. Founded in 2015, the German company chose the 2017 edition of EMO Hannover for its first public appearance. At the time, the metal AM market was still dominated by powder-based technologies. For GEFERTEC, coming to the metal AM market was not only a means to provide another metal alternative to manufacturers who were embracing AM technologies, it was also giving manufacturers who were used to conventional manufacturing processes, the possibility to choose between a milling machine and a metal 3D Printing machine.

Like machine manufacturers here, GEFERTEC delivers a completely integrated WAAM process that includes software and machinery. The company explains that their **arc-and wire-based process** that works with their dedicated CAM software. Here, a build-up strategy for the component is determined and the G-code for the arc-machinery is created.

*"Then, the near-net-shape part is printed fully automatically and in a controlled manner. Through the arc the wire is melted and layed down layer by layer. The finishing process of the printed near-net-shape part is then to be realized on a separate milling – or drilling machine"*, the company said.

From a materials perspective, one notes that up to 600 cm per hour can be produced depending on the material used, be it steel, nickel-based materials, titanium or aluminum. The company also ensures that material utilization is highly optimized compared to metal-cutting manufacturing processes, which enable the operator to save up to 60% in material costs, especially for expensive materials such as titanium.

While no information is shared about how large 3D printed workpieces can be when using a GEFERTEC machine, one interesting application the company shared for this dossier is a project that was conducted for **Deutsche Bahn AG**. The project required the use of their 3DMP® process for the fabrication of mobility-relevant spare parts that are no longer available from stock and sometimes had extremely long delivery times.

*"A typical component is the secondary* ***roll stop*** *required in the bogies of ICE trains. This component limits the transverse play of the railroad car body and thus ensures the safe cornering of the trains in tight track curves"*, the company outlines.

Image: roll stop – Courtesy of GEFERTEC.

With years of expertise behind and many more ahead, GEFERTEC prides itself on being an end-to-end WAAM manufacturing solution that develops and qualifies the individual application for each customer to help them successfully implement WAAM into their production.

**References:**

- Interview with **Wim Verlinde**, IWE, IWI-C, WAAM @ Belgian Welding Institute

- Interview with **Mark Douglass, Lincoln Electric Additive Solutions**

- Research on "Design study for wire and arc additive manufacture"

- "Additive Manufacturing: Foundation Knowledge For The Beginners" – World Scientific

- Examples and WAAM-dedicated solutions and applications. Contributions shared by WAAM3D Ltd, Guaranteed, MX3D, AML3D & GEFERTEC

# FEA…IT'S NO LONGER JUST AN « ENGINEER THING »

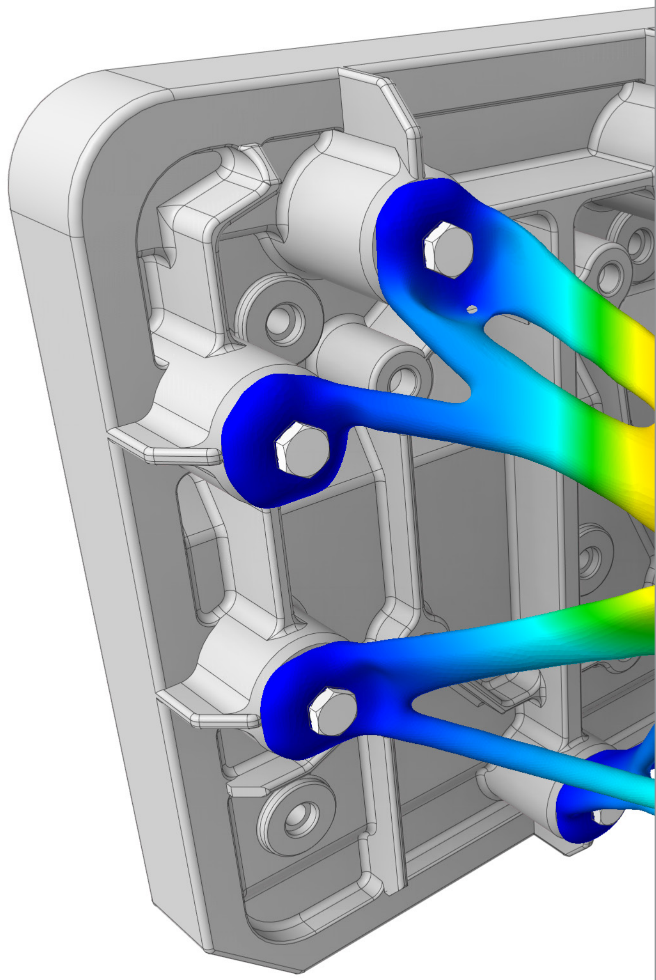


Image: Automotive Bracket Housing showing topology optimization and validation using Ansys Discovery – Courtesy of ANSYS

***Finding a design that works first, predicting what's happening inside the AM machine then.***

The last time I was at a trade fair - before the pandemic hit - I stopped at a booth because a beautiful metal 3D printed part caught my eye. I was looking at it without any idea of what it really took to make it when I heard someone behind my back say: *"the power of Finite Element Analysis"*. I wasn't sure I understood what it meant. I wasn't sure either if the editor in me wanted to discuss a very technical topic that would have probably taken a lot of time to understand. So, I smiled, and I laid my eyes on something else.

However, this sentence stayed in my head, and I decided to learn more about it – about Finite Element Analysis aka FEA. If I should summarize what I learned in one sentence for an end-user, I would say that **FEA is probably the ultimate tool used to give life to many of the products around us today** but this is not a general consumer magazine, it's a trade press. Therefore, I believe, you expect me to dig a little deeper and to do so, I invited software provider ANSYS and manufacturing on-demand service Xometry to share their expertise on the topic.

This article aims to:

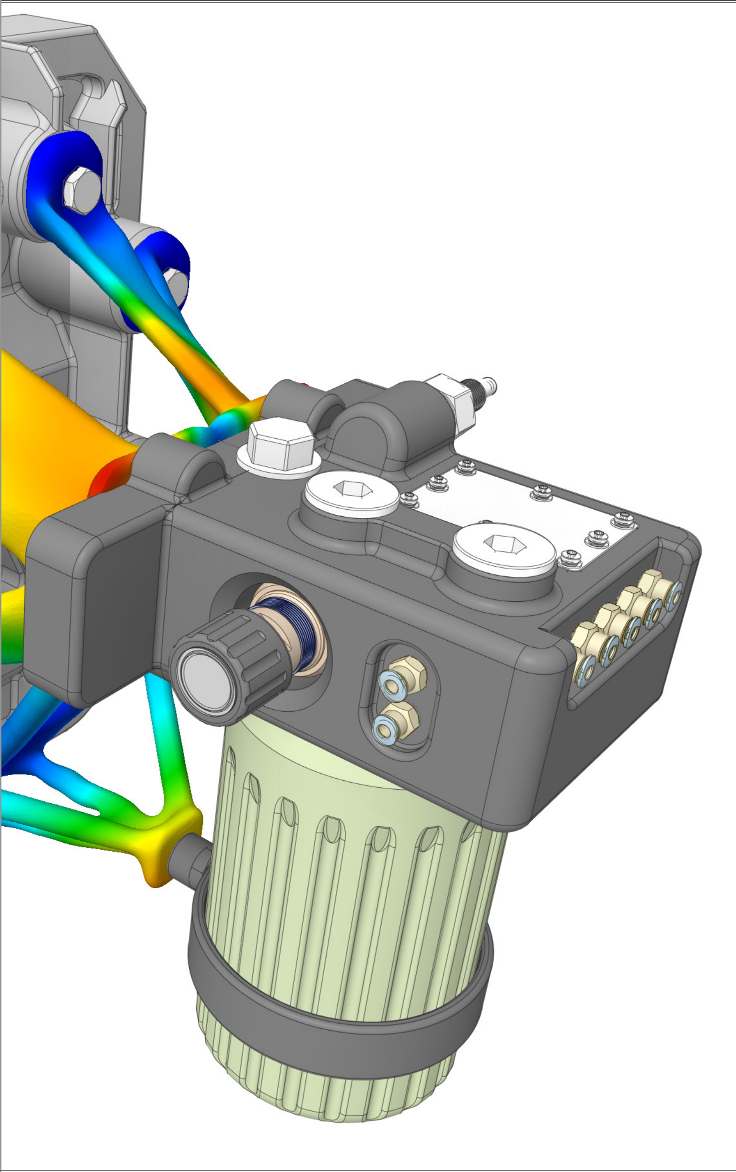
— Shed light on the main uses of FEA in an additive manufacturing production environment and how theory might differ from its practical aspect;

— Present its advantages and complexities in a given AM process: the specific cases of **metal AM** and **FDM** will be taken into account here;

— Provide tips to those who will leverage this tool in their work

## Finite Element Analysis: What? Who? Why?

FEA is a process developed as a means to address structural mechanic problems in engineering. Research shows that mathematician Euler was one of the first to use the concept in the 16th century but a more understandable definition was found in the



works of Schellbach in 1851.

According to **Brent Stucker**, Distinguished Engineer in Additive Manufacturing at **Ansys**, decades ago, when engineers discovered the potential of this method in design, to apply it they had to go through the tedious process of writing equations for each element or a matrix algebra required to obtain the desired solution. The reason was, the method required the engineer to divide a structure into discrete elements which were joined at common points called nodes. Writing equations therefore helped describe the behaviour of each element, so that the method applies loads and boundary conditions, assembles an overall stiffness matrix and solves the set of resulting simultaneous equations.

With the advancement of software tools, the FEA method is more "automated" today. *"The user might not require such calculations because the simulation tools are much more intuitive. They can use machine learning. So a non-expert can still have good results"*, Stucker notes.

With the help of computer-based codes, the engineer can generate solid models of a part, discretize the model into elements, apply loads and boundary conditions, and thereafter wait for the computer to perform the analysis and decipher the results.

## What?

However, the understanding and the main uses of this method remain quite confusing for most professionals today. For **Stucker**, professionals should make a clear distinction between two separate uses of FEA, especially when it comes to the AM process:

*"It's essential to distinguish between using **FEA for the design of the component** and on the other hand, to **predict what's going to happen to that design while it's being built in the AM process**. There are the two separate uses of the FEA process that people sometimes, confuse; and one uses two completely different types of FEA for these two problems."*

This means that the first questions professionals should ask themselves are: **am I predicting the design of the part? Or am I predicting what's happening in the process?** Indeed, when FEA is being use to design a part, the focus here is on the geometries of the part. In this case, it is important to de-risk and to optimize designs before they go into production, whereas when it is used as a process simulation tool, the focus is on the manufacturing itself, on what's going on in the physics of the machine, what will happen to the material used in the machine, etc.

Brent Stucker, Co- founder of 3DSIM LLC, a company focused on commercializing algorithms for predictive modeling of additive manufacturing processes. The company was acquired by ANSYS in 2017.

By combining these two main uses of FEA, **Greg Paulsen**, Director of Application Engineering at **Xometry** explains:

*"FEA helps prove out your design will do what you say it will do in a digital space. Finite Element Analysis is a tool to help predict the results of a design's performance before any physical part gets fabricated. Its advantage is that you can simulate, iterate, and validate your design's "digital twin" without sinking time and cost into manufacturing and mechanical testing. FEA works by assigning material properties to a 3D model as well as environmental conditions and loads. The simulation takes all of these into account to predict if those conditions affect the part's structure integrity, even predicting deformation or critical stress points. Based on FEA feedback, you can modify your design to mitigate these effects or increase a safety factor. Ideally, FEA will help create the intended outcome and performance of your design so that when you build the part, you and your team have data-driven confidence that it will work".*

This is certainly the reason why FEA is seen by most professionals as a cost justification and simulation tool.

## Who (can use it) & Why?

Listening to what the FEA method is might give the illusion that the process is only intended to designers, but Ansys' **Stucker** points out that in the end, the *"main goals of running FEA depend upon your job description."* In other terms, whether you are **a designer, an operator, a material scientist, or a quality engineer,** you might find yourself using an FEA method in one of your tasks.

*"As a designer, it's for making an optimum design that actually performs as intended. As a machine operator, it is to avoid build failure, minimize post-processing costs, maximize machine productivity and achieve part tolerances. As a material scientist, it is to ensure the material microstructure is correct, etc. There are many people who can use FEA to make their AM operations better",* Stucker notes.

No matter what your job description is, the expert ensures that "running FEA can be as easy as using an Excel spreadsheet. For many types of AM simulations, the workflow has been standardized and simplified such that a user without any specialized FEA training can set up a simulation in a couple of minutes".

## FEA, a few of the complexities explained during the product development cycle

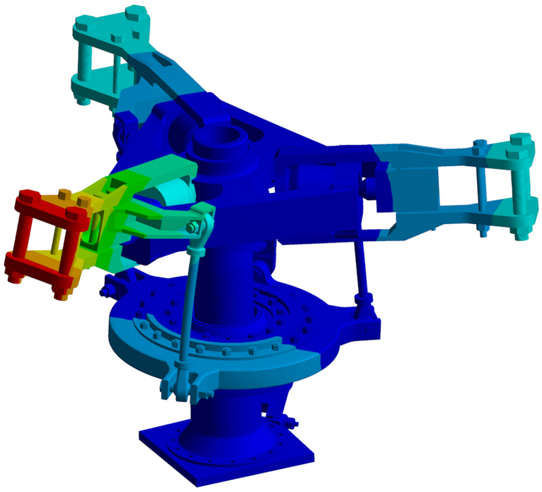
First of all, let's note for those who are new to the field that, FEA programs are usually embedded into computer-aided design (CAD) software, so that engineers can easily go from design to running complex structural analysis.

Here is the thing, as the use of FEA greatly depends on the professional's job description, we came to realize that complexities during the analysis can greatly vary from one person to another and even on the applications.

Indeed, while **structural analysis, heat transfer** and **fluid flow** are often said to be the most common problems in FEA for instance, it turns out that they can only be the main challenges for those who design a component.

A closer look at heat transfer for instance, reveals that FEA might be particularly useful when seeking to control thermal issues in a machine. Ansys' expert states that the first thing to note is that one may not want the thermal characteristics to be the same for every region of a part.

*"It may be beneficial to change the thermal characteristics locally, thus producing varying microstructures and properties in different regions of a part to optimize the part's performance. To manage thermal issues, you must control both the heat input and the heat output. Heat input can be controlled by changing the machine energy inputs like laser power, scan speed, heater temperatures, etc. Typically heat output is changed by things like adding delays to increase cooling time, adding thermal supports and heat sinks, using active cooling in the chamber, etc.",* he continues.



Caption: Ansys Mechanical showing best-in-class finite element solver with structural, thermal, acoustics, transient and nonlinear capabilities to improve your modelling. Courtesy of ANSYS.

This is just one in a myriad of potential complexities. And even here, if you look very well at these most commonly mentioned issues, **recent advances in this method might reveal improvements in methodology and mesh adaptivity, as well as techniques to improve the efficiency and estimate the error bounds.**

As Stucker says, there are many other problems that FEA can help with: semiconductor chip design, manufacturing process optimization, to name a few The question is, if you are new to the field and you do not have some of the *"newer FEA packages, like Ansys Discovery, which make FEA easy, intuitive and almost instantaneous"*, **can this method slow down the product development cycle?**

We have asked this question to **Xometry**:

*"Deciding on the inputs critical to your design's success can often be time-consuming because those can be conditions outside of your control and require research. Most designers are working with a general understanding of the process and materials they are using to get a good start on the design approach. With additive manufacturing, you have access to rapid prototyping services with lower costs and short lead times. You can work in parallel by building physical products and defining the simulation to help validate*

*other design features outside of the FEA's goal.*

*What is very compelling is how 3D design software blends design and FEA through a generative design process. Generative design takes advantage of the complexity level a 3D printed part can have and builds features around similar constraints used in FEA without the need for the part to be traditionally designed. Part features digitally form and connect based on FEA inputs. Compared to using a generative design approach, traditional FEA can be compared to using a road atlas for driving versus a navigation app--it is a step-change in functionality. Results of generative design simulations can turn into the actual part used or a template used by the designer to optimize for their intended manufacturing outcome.*

*FEA, from our experience, does not slow the Production Development Cycle down but allows engineering teams to contemplate and delve into deeper root failure issues/experiments before releasing the end-product. They are no longer looking at the surface level failures of the traditional it1, it2, or it3 as FEA has quick situational analysis feedback. This now allows the engineering team more time to push the boundary of product capability."*

Greg Paulsen, Director of Application Engineering at Xometry

## FEA, a look at the manufacturing processes: the specific cases of metal AM and FDM

Sometimes, even when your primary intention is not to compare AM processes and conventional manufacturing processes, you find yourself realizing how conventional manufacturing principles continue to influence additive manufacturing production.

In this vein, FEA was fundamentally developed with isotropic properties of parts in mind which means that all physical characteristics of the parts are similar in all directions In AM, material is always continuously added during manufacturing, thus building the piece in a vertical direction and creating orthotropic parts, that are generally weaker.

That's why, whether you manufacture with a metal AM or an FDM 3D printing process, you may be required to consider minimum manufacturing feature size, orientation effects, need for supports, and other machine-specific and material-specific characteristics.

An **analysis of the use of FEA for the production of a metal 3D printed part and the production of an FDM 3D Printed part reveals some similarities and differences**. – *(The analysis is based on our guests' responses to our questions).*

| | Metal 3D Printing | FDM 3D Printing | Remarks |
|---|---|---|---|
| FEA method of the design | Use of FEA is pretty much the same than for an FDM 3D printed part | Use of FEA is pretty much the same than for a metal 3D printed part | Material properties need to be updated. Dramatic changes in properties like tensile and flexural strength may be observed in FDM production |
| FEA method of the manufacturing process | Different FEA process: Using standard FEA for metal parts is overall fine if the values used are based on the weakest direction | Different FEA process: careful consideration of the inputs used should be considered. | FEA tasks (design and manufacturing process) are similar in that they both involve a moving heat source where a part is being created scan by scan and layer by layer to make the 3D object. Deformation occurs over time and must be tracked in both types of FEA tasks.<br><br>Any type of distortion compensation you might want to do would be similar for both processes (FDM & metal AM). |

No matter how clear this table can be, some of the hidden complexities in the use of FEA for a given process might often reveal themselves when the engineer will be confronted with a real production case.

In **Paulsen**'s experience, "*designing for 3D printed metal parts often favours the opposite drivers of design for machining. For example, CNC parts often retain thick, bulky features where a direct metal laser sintered (DMLS) part is best designed using thinner, more organic features. Some of these features may even be impossible to produce traditionally, such as lattice structures and curved internal channels. When simulating a part designed for DMLS, it may be difficult on the setup and more time-consuming during computation due to the extensive mesh data associated with highly complex parts.*

*[On the other hand], FDM parts can be significantly weaker in one direction due to the build orientation used. FDM may be better represented as a series of wafers with the thickness of the layer height having the planar (stronger) properties with an adhesive bond between each layer representing the vertical (weaker) properties. That is easy to write but can be challenging to do in practice.*

*In many cases, FDM 3D printed parts can be intended to deform, unlike many metal structures that may require stability. Certain metamaterial applications can be achieved with flexible polymer lattices. A great example is creating digital foams, where an elastomer is built using different densities of lattice to create softer or firmer behaviour upon pressure.*"


Image: MJF 3D printed part. Via Xometry.

## So, what else?

At first glance, FEA sounds very complex to understand and thus to leverage, but when you start scratching the surface, you feel the need to dig deeper and deeper and you realize that FEA upgrades as well as latest advancements in the field from software providers could fill an entire magazine.

Interestingly, for many years, FEA usage was primarily limited to specialized engineers who were adequately trained for the purpose. Today, with the development of machine learning tools, almost any designer or engineer can find easy-to-use FEA packages that will make their job easier and more productive. Indeed, software providers such as **Ansys** deliver various tools to help designers create better designs, to support machine operators in the optimization of their process and to set up their builds effectively, quality engineers certify their parts more effectively; material scientists control the microstructure, and more.

Image: Xometry tiles – Courtesy of Xometry.

However, as far as FEA is concerned, Ansys is specifically "*looking at significantly simplifying our workflows, and expanding the types of machines and materials that [one] can simulate*".

From a user perspective, FEA is just one of the many tools that can be used by engineers across vertical industries adopting AM technologies and service bureaus. From that standpoint, **Xometry's Paulsen** lays emphasis on the fact that additive manufacturing tools for CAD, FEA, and generative design software are still lacking or difficult to access, despite the significant improvements.

"*Building tools to help define orientation, having an updated library with industry-agreed properties of different 3D printed materials and processes, and simplifying the process will all help. It is important to note that additive manufacturing can produce parts on demand with instant quoting at any time. FEA and similar tools can often aid in engineers getting the most out of the process for high-performance, weight reduction, part consolidation, and more*", he adds.

Last but not least, it should be noted that "not all parts require FEA or complex digital simulation. When they do, that is performed by the designer or engineer using the *"digital twin" methods to produce and iterate without the physical production.*"

In the end, those who do not want to rack their brains with all these design and manufacturing constraints can just upload their file for instant pricing and lead times at the manufacturing on demand service of their choice, configure it based on their needs and just wait for it to be built.

**References:**

OpenLearn, Introduction to finite element analysis, https://www.open.edu/openlearn/science-maths-technology/introduction-finite-element-analysis/content-section-1.1#

Interviews with **Xometry & ANSYS**

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# HYPERGANIC

## ALGORITHMS AND AI, THE MISSING PIECES IN THE ADDITIVE MANUFACTURING GAME


*Tech companies that emerge out of anonymity often do it with a bang: through a big launch event to capture the public's attention or by announcing a seed round but I strongly believe the key in sparking interest lies in the way a company explains how it can transform industries. The latest company that decided to turn stealth mode off is* ***Hyperganic*** *and I sat down with CEO & Founder* ***Lin Kayser*** *to understand the transformation they ambition to bring to the AM industry.*

Headquartered in Munich, Germany, **Hyperganic**, in simple terms, develops and provides a software platform for advanced design and engineering of parts, structures and entire machines of extreme complexity. What makes them outstanding? **Artificial intelligence (AI) and algorithms**. As per Kayser's words, they *"create the design of physical objects using AI and algorithms." "We mass produce them in digital factories that have AM at their heart. Our goal is to radically accelerate innovation and it all starts at the design level with engineers who want to create new objects. The truth is, there is a lot of manual work involved in the work of designers. They have to match things in their head and put them on their screen. The process is like building every single façade of the building you want to build. At Hyperganic, we take the thought process of the engineer which requires to answer the question "how do I build something?", we put it into algorithms and then, the algorithms can automatically recreate parts that otherwise the design engineer would create. The algorithms brings him to the next level to help him produce the things he would like to see and that's the key enabler of AM."*, he adds.

According to Kayser, a big number of manufacturers do not see the utilization of AM beyond prototyping or small batch runs. Therefore, when it comes to mass production, they often think of another manufacturing process. The Hyperganic team wants to enable this mass production and wants to do so especially for the most complex parts that may absolutely require AM. In Kayser's opinion, such type of parts are so *"tailored to AM, so advanced that not only does AM make sense in terms of functionalities, but also financially and for mass production".*

Lin Kayser, Founder & CEO of Hyperganic, Software company

## How it started…

Well, Kayser didn't just wake up one morning and decide to create a company dedicated to the additive manufacturing industry. As a matter of fact, his entrepreneurial journey started thirty years ago. The software expert's previous company specializes in digital image processing for the Hollywood industry. Over time, he got dissatisfied with what he was doing. The turning point came when he listened to Al Gore' speech on "climate change" entitled ***"An Inconvenient Truth"***. Just as everyone (or almost everyone) does on a daily basis, he was doing his part, - sort his waste – but was not aware of the much more important global challenges.

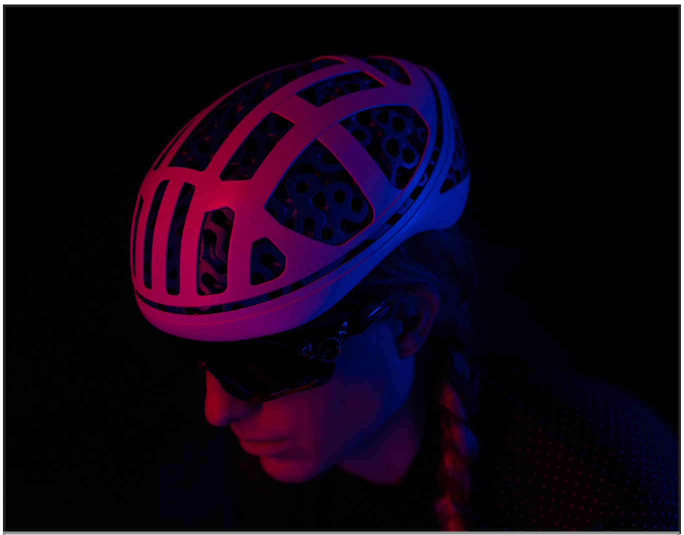
He decided to sell his company in 2011 and started thinking about how he could come up with a significant contribution.

*"For me, innovation was something that was happening fast but only in very specific fields like computing or IT but when we look at physical objects, nothing has changed that much in decades. I can't help but think that was one of the issues to address, in order to be more sustainable, to move forward faster and solve some of the issues we were facing at a global level. Fortunately, in 2012, I stumbled across 3D printing and I was hooked"*, he recalls. The thing is, the software guy in him knew that coding and software development was one of the most creative things someone with his background could do, because *"you imagine something in your head and you give life to it. But it's hard to do it physically because software is virtual." "When I discovered 3D printing [hobby 3D printers], I realized that it is a machine that can essentially prints codes"*, he notes.

Needless to say, his learning curve brought him to industrial 3D printing that can process almost any materials but the process has been held back by the models that we send to the 3D printers. Remember that study that reveals that "44% of parts that arrive at digital manufacturing service bureaus do not have a 3D model"?

*"We are designing these models in a traditional way of creating CAD models for physical objects. We have been doing that for the last 15 years or so. I started asking myself if we could use computer codes to build physical objects. Instead of modelling something visually, can we use AI and algorithms to create physical objects, structures and maybe entire machines? That was in 2014 and that's how the idea for Hyperganic was born"*, he explains.

Together with **Michael Gallo**, CTO of his previous company and current CTO at Hyperganic, they sat down, discussed this idea, and hesitated. They finally started developing a software platform where they could basically store every molecule of a part; in other terms, *"a workflow that will create various variations of different parts in order to automate the work of the design engineer so that designing becomes finding the right object in these variants"*. This means that in the operating systems they create, one could automatically designs objects of a similar type. Therefore, the final look of the end-part will depend on the environment and the parameters the design engineer would have fed into the algorithm. That was in 2017. Hyperganic was officially founded



AI-Designed 3D printed cycling helmet – Courtesy of Hyperganic

Hyperganic took off and in a few years, has built a growing base of customers across Europe, the US, China and South East Asia. Early at the beginning of this year, the company secured a **funding round of $7.8M** to expand the team and continue the development of its software platform.

German funds **HV Capital** and **VSquared Ventures** led this first VC investment round for Hyperganic, and co-investors included US-based Converge, industrial partner Swarovski and PC pioneer Hermann Hauser, co-founder of ARM.

At the heart of the developments of the company, there are the **Hyperganic Core** and **Hyperganic Print Framework** platforms.

According to Kayser, the first product is a voxel-based geometry platform for AI-based and algorithmic design. This means that voxels help to define geometry be it at normal or higher resolution of the printer. It is available on desktop and as a scalable cloud application platform. The second product on the other hand, aims to support print preparation and highly precise process control.

Interestingly, for those who like to categorize software providers in the AM industry – assuming that Design (CAD), Simulation (CAE); Processing (CAM), Workflow (ERP/MES), as well as QA & Security are the five key categories that might help manufacturers understand what a software does, it would be hard to only check one box (in the case the "Design" category) for Hyperganic.

*"We do much more than just the "design" part. We can ensure mesh repair, slicing, support generation, nesting, stacking, voxel-level process control and even multi-material support"*, Kayser explains.


Part of rocket engine – AI-designed and 3D printed – Courtesy of Hyperganic

## How does Hyperganic platform do what it does…

The Munich-based company has developed a software platform that is compatible with any industrial 3D printing platform.

*"We work with polymer 3D printers, metal AM technologies, resin-based systems. We even support manufacturers who print with concrete. We cover the full spectrum of materials on the market"*, the CEO outlines.

Rocket engine – AI-designed and 3D printed – Courtesy of Hyperganic

Users of the Hyperganic Core platform can explore and create a broad variety of applications, including **aerospace, consumer goods**, and **medical** products. What's interesting to keep in mind is that these products **absolutely need to be customized**, they can be **super complex** since they require voxels to be created or they should be **highly optimized objects**.

Amid the AI-design based objects, Hyperganic's platform has already helped to create, there are for instance a **3D printed cycling helmet** or even a **3D printed rocket engine**. However, it should be noted that the company currently focuses on **aerospace applications.**

As far as the rocket engine is concerned, the team decided to explore an entirely algorithmic approach for its creation.

*"We decided to give the algorithms just one geometric starting point, a spline curve that describes the inside of the combustion chamber, stored in an Excel spreadsheet. There were no CAD files, no existing models, just data, stored in a spreadsheet, plus the algorithms that interpret the data to generate the functional parts of the engine. With this minimal starting point, we built the algorithm that generates the actual geometry. The engine is created top to bottom, laying out channels that transport the cryogenic oxidizer first down around the chamber, cooling the inner wall that is exposed to the burning fuel, and then back up again in an outer layer of channels, for later injection into the chamber itself. We used Hyperganic's capability to precisely control the process parameters for every point in space to modify the structure of the metal itself. The inside of the chamber is printed very densely, using high laser power, whereas the outside becomes almost porous to keep the weight down"*, a company's report reads.

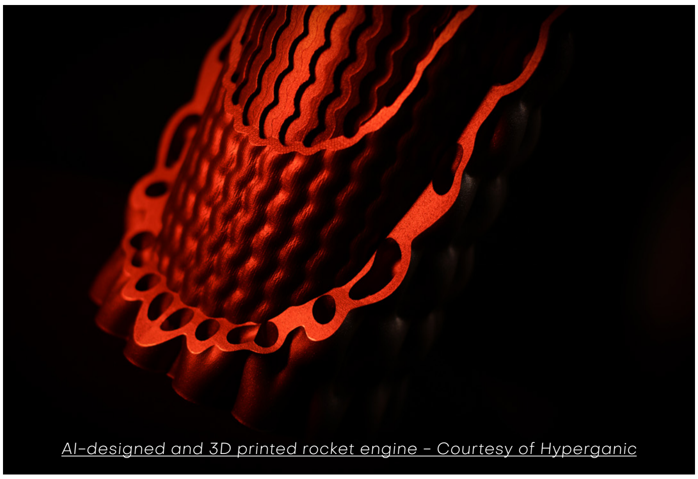
The difference with traditional engineering is that here, the engineer does not design a part in a linear fashion; he rather creates a process that leads to the desired part.

*"Traditionally you start with an existing solution and make incremental changes. In Hyperganic engineering, you regenerate objects from scratch all of the time. You generate hundreds or thousands of variants that can be evaluated. In traditional engineering, redesigns are costly and need to be avoided; in Hyperganic engineering, it is the norm and the key to coming up with a global optimum"*, the report highlights.

## What's next for the company?

From a business standpoint, the company is currently expanding its customer base beyond simple users (design engineers) to reach third parties who would like to use the platform to create their own applications.

Moving forward, Kayser strongly believes that AM will not stay a niche forever. On the contrary, for him the technology will become one of the most important fields in manufacturing in a few years. *"By bringing algorithms into this game, we create a new type of manufacturing that has not been done before. We are providing that missing piece that will lift AM to a new level"*, he concludes.



AI-designed and 3D printed rocket engine – Courtesy of Hyperganic

# EXPERT COLUMN

## POWDER SUPPLY: Relevance Of New AM Developments FOR AM Supply Chain

**Words of Kenan Boz.** *Technical Manager at the European Powder Metallurgy Association, he demonstrates some of the research undertaken as part of the EU's SAM Project.*

***Additive Manufacturing currently creates a brand-new market for powder suppliers, even though it requires more strict qualifications of material supply in terms of metal powders. On the other hand, the increasing expansion of the digital marketplace beyond traditional retail business models changes the way supply chain professionals must work, therefore the way orders are being processed and fulfilled. The article below takes a closer look at the powder supply chain, as well as the variables that may influence the production of metal AM powders as compared to powders produced for conventional manufacturing processes.***

Custom products have been common in road cycling A supply chain is a system of organizations, people, activities, information, and resources involved in supplying a product or service to a consumer. Supply chain activities involve the transformation of raw materials, resources and components into a finished product that is delivered to the end customer [1]. In sophisticated supply chain systems, used products may re-enter the supply chain at any point where residual value is recyclable. Modern consumers are expecting to receive their orders sooner than ever before. The digital marketplace continues to expand beyond the traditional retail business model every day and consequently, customer expectations grow. This has changed the way that supply chain professionals must work to ensure orders are processed and fulfilled.

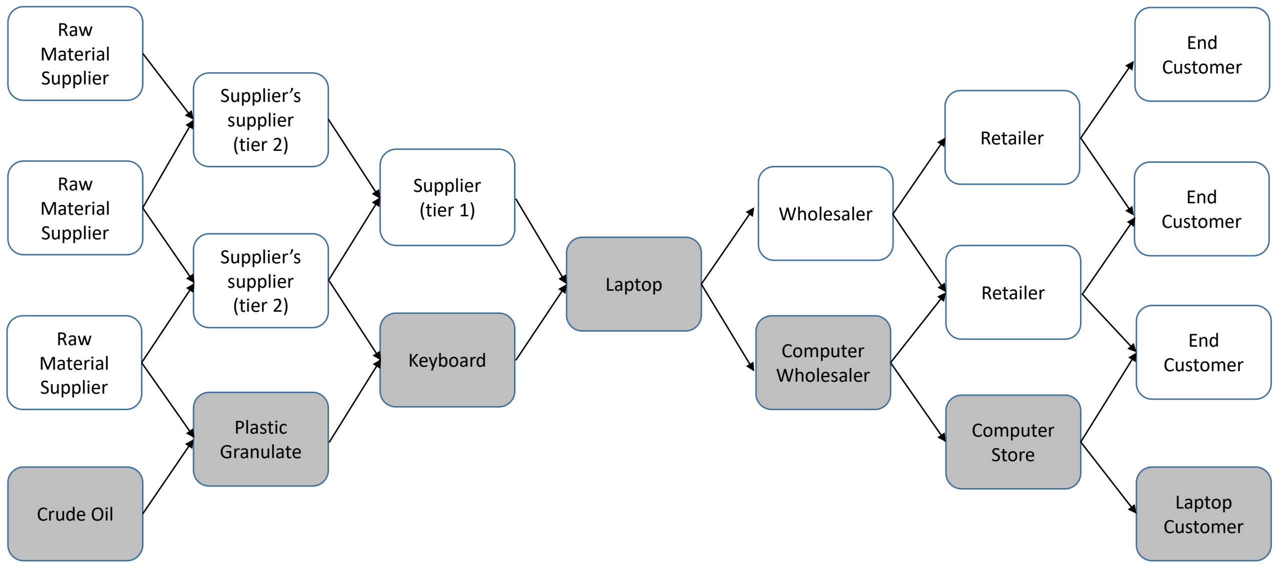



Figure 1: A typical example of a supply chain for a laptop computer [2]

A typical supply chain (Figure 1) begins with the ecological, biological, and political regulation of natural resources, followed by the extraction of raw material, and includes several production links (e.g., component construction, assembly, and merging) before moving on to several layers of storage facilities of decreasing size and increasingly remote geographical locations, and finally reaching the consumer. Many of the exchanges encountered in the supply chain are therefore between different companies that seek to maximize their revenue within their scope of interest but may have little or no knowledge, or interest in the remaining players in the supply chain. Shortly, a chain is actually a complex and dynamic supply and demand network.

**Additive manufacturing** is seen as a disruptive technology for supply chain management because of its characteristics. Holmström et al. [4] highlight the following benefits of AM methods over the conventional manufacturing methods as:

· No tooling required

· Feasibility of producing small production batches in an economical way

· Possibility for quick changes in design

· Product optimization for functionality

· More economical custom product manufacturing with the capability to produce complex geometries

· Potential for simpler supply chains with shorter lead times and lower inventories

In addition to above benefits, there is the **possibility of reducing material waste** by as much as 90% according to a report by Markillie [5] on AM. Traditionally, raw materials or components are supplied from suppliers, assembled in manufacturers and shipped to customers through retailers or distribution centers. On the contrary, Additive Manufacturing technology enables organizations to bypass the traditional supply chain and manufacture a product themselves with a digital design (Figure 2).

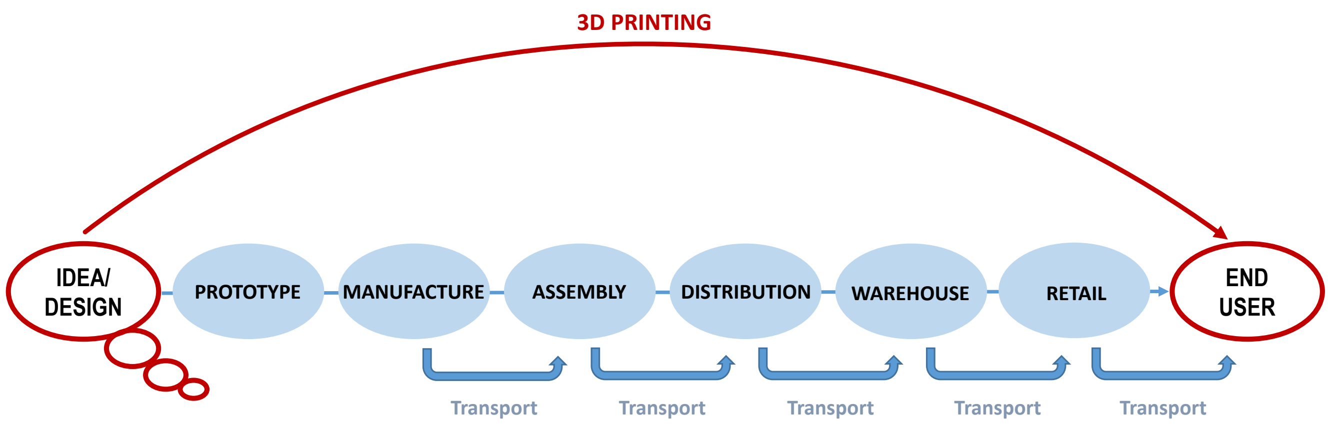



Figure 2: Traditional versus AM supply chain [3]

Nowadays, many companies integrate AM Technology into their supply chains. The average annual growth rate of worldwide revenues produced by all products and services over the past 30 years of Additive Manufacturing is 26.7%, where the growth within the four years from 2016 to 2019 is more than 23%. The Wohler's report states that the total AM industry achieved a size of $12.7 billion by the end of 2020.According to **Lux Research** from Boston-USA, the value of additively manufactured parts is to rise at a 15% compound annual growth rate (CAGR) from $12 billion in 2020 to $51 billion in 2030. AM is a growing means to produce both prototypes and products.

## Powder Supply Chain

There are a number of methods available to produce metal powders including such as solid-state reduction, electrolysis, various chemical processes, atomisation and milling. Historically, for reasons rather commercial, atomisation has been identified as the best way to form metal powders for AM regarding the geometrical properties of the powder it yields. **Table 1** summarizes powder characteristics obtained by different manufacturing processes.

The production of AM metal powder generally consists of three major stages as outlined in the flow diagram shown in Figure 3. Briefly, the first stage involves the mining and extracting of ore to form a pure or alloyed metal product (ingot, billet and wire) appropriate for powder production; the second stage is the production of the powder and the final stage is classification and validation. The supply chain of taking ore and extracting a metal is well established and supplies a vast range of pure metals and specific alloys to global markets.

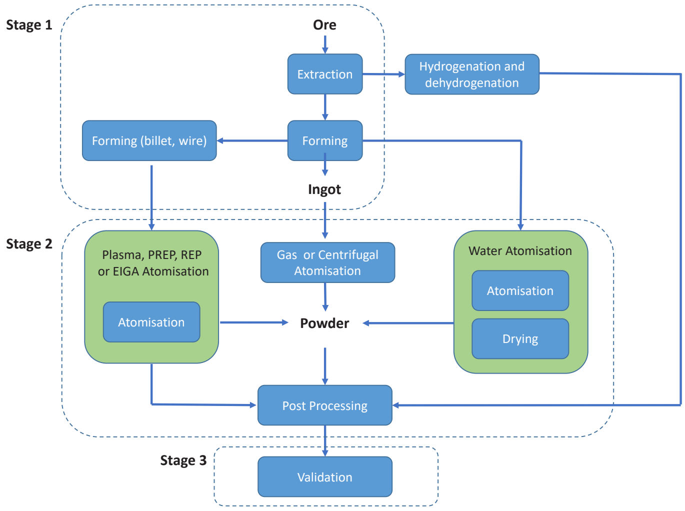



Figure 3. Powder production steps flow chart from ore to validated AM powder [6]

Once an ingot of the metal or alloy has been formed, a number of additional processing steps may be required to make the feedstock suitable for the chosen atomisation process. For example, plasma atomisation requires the feedstock material to be either in wire form or powder form, thus adding additional rolling and drawing work or a first step powder production route.

| Manufacturing Process | Particle size, µm | Advantages | Disadvantages | Common uses |
|---|---|---|---|---|
| Water atomisation | 0–500 | High throughput<br>Range of particle sizes<br>Only requires feedstock in ingot form | Post processing required to remove water<br>Irregular particle morphology<br>Satellites present<br>Wide PSD<br>Low yield of powder for 20–150 µm | Cu, Al (Non reactives) |
| Gas atomisation | 0–500 | Wide range of alloys available<br>Suitable for reactive alloys<br>Only requires feedstock in ingot form<br>High throughput<br>Range of particle sizes | Satellites present<br>Wide PSD<br>Low yield of powder between 20–150 µm | Ni, Co, Fe, Ti, Al |
| Plasma atomisation | 0–200 | Extremely spherical particles | Requires feedstock to either be in wire form or powder form<br>High cost | Ti (Ti64 most common) |
| Plasma rotating electrode process | 0–100 | High purity powders<br>Highly spherical powder | Low productivity<br>High cost | Ti |
| Centrifugal atomisation | 0–600 | Wide range of particle sizes with very narrow PSD | Difficult to make extremely fine powder unless very high speed can be achieved | Solder pastes, Zinc of alkaline batteries, |
| Hydride–dehydride process | 45–500 | Low cost option | Irregular particle morphology<br>High interstitial content (H, O) | Ti6/4 |

Table 1 : Powder Characteristics by Manufacturing Processes [6]

## Two main variables that may influence the use and production of metal AM powders

### *Particle Size and Morphology*

Particle morphology has a significant **impact on the bulk packing and flow properties** of a powder batch. Spherical, regular, and equiaxed particles are likely to arrange and pack more efficiently than irregular particles. Research into the effect of particle morphology on the AM process has shown that morphology can have a significant influence on the powder bed packing density and consequently on the final component density; where the more irregular the particle morphology, the lower the final density. As a result of this, **highly spherical particles tend to be favoured in the AM process**. Figure 4 shows various morphologies of iron powder achieved by different production methods.

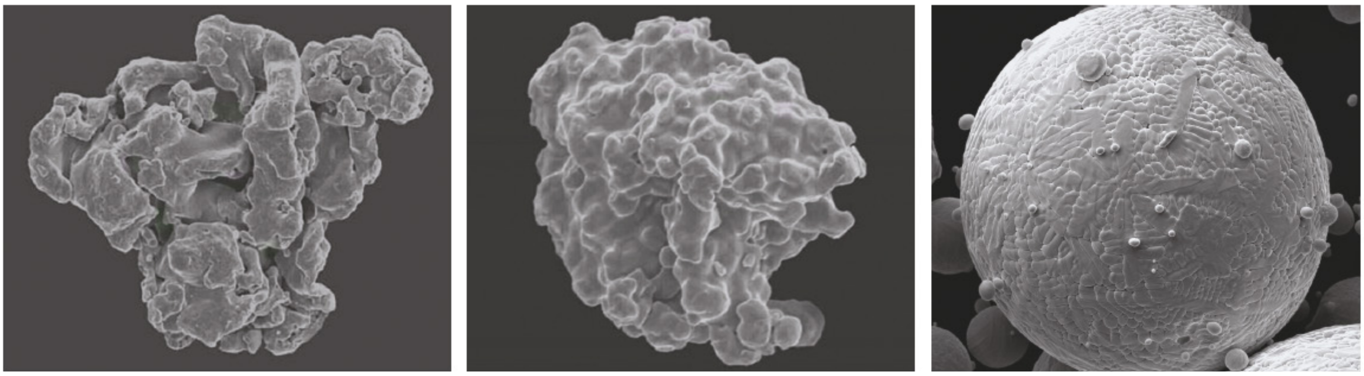


Figure 4: Examples of powders with different morphologies. [8]

The **particle-size distribution** (PSD) is a list of values or a mathematical function that defines the relative amount of particles present according to size. It can offer the information regarding the particle size span width, and D10, D50, and D90 (as known as D-value or three-point specification) is the most widely used values in PSD analysis. Those values indicate the particle diameter at 10%, 50%, and 90% of the cumulative distribution. Characterisation of Particle Size Distribution (PSD) in a batch of powder ensures that the optimum range of particles, by size, are used in each process.

In general, **Electron Beam Melting** uses a nominal PSD between 45–106 m, whilst L-PBF uses a finer range between 15–45 m, and Binder Jetting between 5–30 m. PSD will have an obvious impact on both the minimum layer thickness and the resolution of the finest detail in the component.

An inappropriate combination of PSD and layer thickness can potentially lead to **in situ segregation due to the mechanical re-coater pushing coarser particles away from the bed**, segregation in this sense could lead to variation in build quality in the vertical direction. It is generally well reported that using powders with a wide PSD and a high fine content produce components with a higher fractional density. However, the use of fine materials increases the risk of health and safety issues. This is particularly true when processing reactive materials such as titanium where finer particulates are likely to be more flammable and explosive. In 2011, a terrible accident took place at Hoeganaes facility in Gallatin, USA with 3 injuries and 5 deaths, due to an explosion of fine metal dusts at nanoscale that were piled up in various areas of production [7].

### *Powder flowability*

**Powder flowability** is an important technological requirement for powders used in AM. The density homogeneity of the final part depends on the layer-by-layer melting being performed on thin and uniform layers that are accurately deposited by the feeding device. Cohesive powders which exhibit poor flow properties are likely to be more problematic in

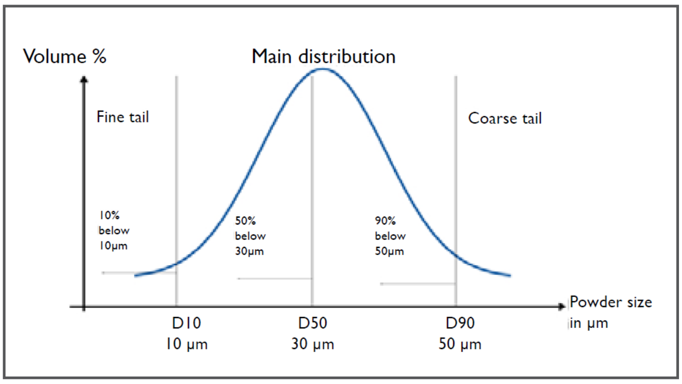



Figure 5: Example of D10, D50 and D90 on a PSD curve for a 10-50 microns powder

terms of obtaining homogenous density layers throughout the build than powders which are comparatively more free flowing. Powder flow is difficult to relate to any one given parameter of a powder but there are some general rules which can typically be applied:

(a) Spherical particles are generally flowing better than irregular or angular particles

(b) Particle size has a significant influence on flow. Larger particles are generally more free flowing than smaller particles

(c) Moisture content in powders can reduce flow due to capillary forces acting between particles

(d) Flow properties often show a dependency on the packing density at the time of measurement – powders with a higher packing density are less free flowing than powders with a lower packing density

(e) Short range attractive forces such as van der Waals forces, electrostatic forces and humidity can adversely affect powder flow and may cause particle agglomeration (short range forces have a bigger impact on finer particles)

Although spherical particles with a good flowability are considered to be the most effective ones for AM, as different technologies of AM evolved within the recent years, each one has come out with different requirements of particle size distribution, as mentioned above.

## Conclusions

Using additive manufacturing in the supply chain brings in many advantages in comparison to conventional manufacturing methods. There is less room for human induced error in the supply chain with AM. This results in a 'first time right' production with a lower lead time. Direct shipping becomes an option in the supply chain with AM, and manufacturers can reduce their dependency on different suppliers.

AM drives in decentralized manufacturing, where logistics companies will no longer have to transport finished goods though the globe. However, the last mile delivery of products will increase. Companies need to be agile enough to counter disruptions of this magnitude. The Logistics provider in fact becomes a manufacturer within this new world.

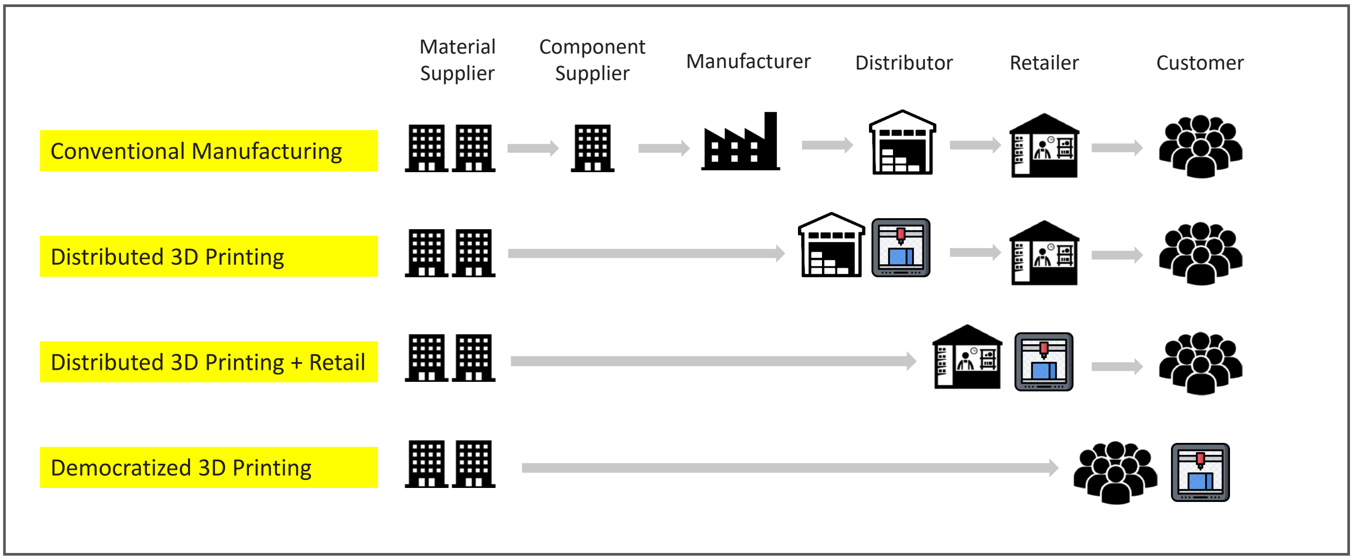



Figure 6 : AM at various levels in the supply chain [9]

AM is definitely creating a brand-new market for powder suppliers, even though it requires more strict qualifications of material supply in terms of metal powders. This narrows the band of usable powder in an ordinary powder production, making the efficiency decrease in comparison to production of powders used in conventional methods such a Press & Sinter. Because of this, price per kilo of powder for the AM market is much higher than the price for the traditional PM market. According to a past report by Roland Berger, increased competition for powder supply reduces today's markups and increasing production volume reduces costs. As an example, steel powder price for AM in 2013 that was more than 90 Euro/kg on average, has dropped down to less than 50 Euros/kg in 2021, which is still expensive more than twice the price of the conventional steel powder. As AM industry gets mature, material prices will settle down to reasonable values in the market.

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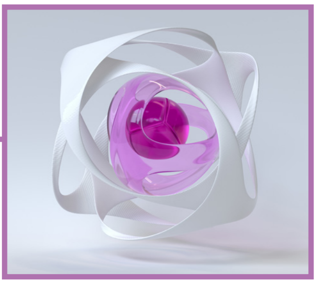
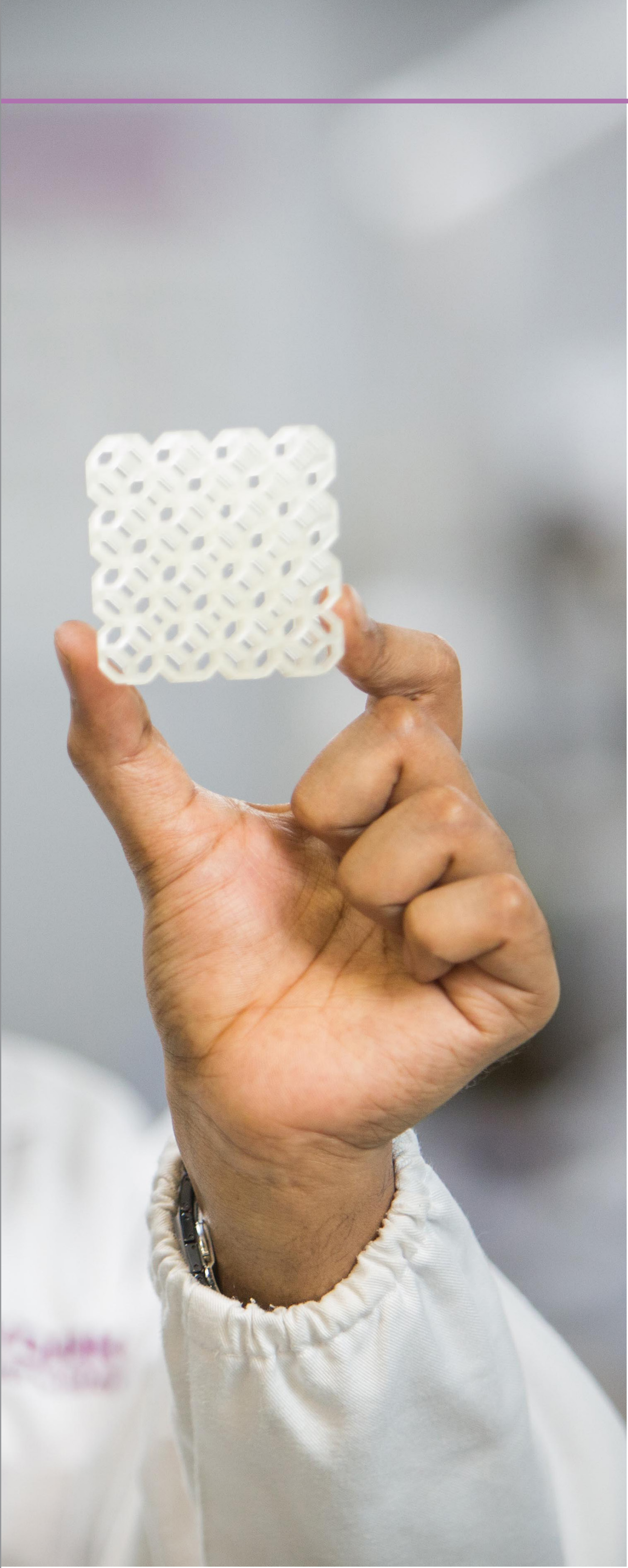
# EVONIK LAUNCHES NEW PRODUCT LINE OF PHOTOPOLYMERS FOR 3D PRINTING

Capture: Evonik strengthens its market position in the long term by entry into photopolymer 3D printing technologies (©Evonik



**Evonik is further expanding its business in the area of additive manufacturing. The specialty chemicals company has developed two photopolymers for industrial 3D printing applications and introduces them under the brand names INFINAM® TI 3100 L and INFINAM® ST 6100 L. The two ready-to-use materials mark the start of a new product line of polymer resins suitable for use in common vat polymerization technologies such as SLA or DLP.**



*"With the new product line, we are entering the market-relevant photopolymer technology stream, strengthening our long-term market position as materials experts for all major polymer-based 3D printing technologies,"* says **Dr. Dominic Störkle**, Head of the Additive Manufacturing Innovation Growth Field at Evonik. *"With the new ready-to-use formulations, we are also continuing our materials campaign and driving industrial-scale 3D printing as manufacturing technology along the entire value chain."*

### New photopolymer product line

The first high-performance material from Evonik's photopolymer product family leads to high toughness and impact-resistant 3D parts. The combination of properties makes INFINAM® TI 3100 L the new standard for additive manufacturing of industrial components using VAT polymerization technologies such as SLA and DLP. The toughness of the printed components is 30 J/m3 with a high elongation at break of 120 percent. The new material can therefore withstand strong impact or permanent mechanical effects such as pressing or impact. The range of possible applications extends from industrial to automotive parts and individual applications in the consumer goods sector, which, in addition to design-free forms, require strong mechanical loads in object use.

The second formulation with the brand name INFINAM® ST 6100 L is setting-up a new benchmark in the category of high strength polymer resins. It combines tensile strength of 89 MPa, flexural stress of 145 MPa and HDT of 120 °C which fills the material gap in ultra-high strength photopolymers. These special properties make INFINAM® ST 6100 L the material of choice for applications which need high temperature resistance combined with high mechanical strength.

*«With INFINAM® TI 3100 L and INFINAM® ST 6100 L we have brought the group's first photopolymer materials for additive manufacturing to market maturity. In doing so, we draw on the enormous chemical expertise of our researchers in component development and formulation. On this basis, we can offer the market a unique product with excellent properties and help our customers to conquer new application areas,»* says **Dr. Rainer Hahn**, Head of Evonik's photopolymer market segment in the Additive Manufacturing Innovation Growth Field.



### INFINAM® Photopolymers for SLA and DLP

The new photopolymers are ready-to-use, high-performance formulations that can be processed on a wide range of common SLA and DLP machines commercially available on the market.

Evonik bundles its expertise in 3D printing in the group's additive manufacturing innovation growth field. The strategic focus here is on the development and manufacturing of «ready-to-use» high-performance materials along with common technologies. In this context, Evonik recently reorganized its product range of ready-to-use 3D printing materials under the new INFINAM® brand. Collaborations with customers and partners are an important innovation driver.

To give an example, Evonik acquired a minority stake in Chinese company UnionTech through its Venture Capital unit in late 2020 to get an accelerated market access for the new photopolymer products. The Shanghai-based company is the market leader in Asia for ultra-large size industrial printers. The company develops and manufactures printers, supplies printing materials through subsidiaries and offers additive manufacturing as a service provider.

"*We draw on necessary resources to constantly develop new materials, expand our production capacities, and bring external expertise in-house. All these measures create the general framework for us to be at the forefront. Our years of expertise in polymer chemistry are the basic prerequisite for our success. In addition, we have built up a strong network with our industry partners over the years. Within those networks, we actively shape the market and set trends to always stay one step ahead*", concludes **Störkle**.


Capture: Evonik bundles its expertise in 3D printing in the group's additive manufacturing innovation growth field. (©Evonik)

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# A CLOSER LOOK AT THE AUTOMATED DYEING PROCESS FOR 3D PRINTED PARTS

3D Printed bracelets – coloured by CIPRES GmbH – Courtesy of CIPRES GmbH

In the textile industry, dyeing is acknowledged as a pivotal process that provides colour to fabrics. In the additive manufacturing industry on the other hand, the ultimate goal remains the same: provide colour to ready-made 3D printed products but the technological process that enables to deliver these end-products is not always well depicted.

The truth is, for several decades, **pot dyeing** has been the standard for manufacturers who wanted to give a certain colour to parts. It requires the operator to have a basic pot, a textile dye and water. The textile dye is mixed with pre-heated water, and thereafter, the parts are immerged in the dyebath for a certain time. Despite its simplicity, the process started raising some concerns & questions:

- The fact that it is a manual operation means that operators often require more time and a lot of pots if they are dealing with a voluminous production batch, not to mention that this might lead in the end to a more expensive final product;

- Uncertain reproducibility. Complex geometries of parts, wall thicknesses or stirring tempo are some of the items that may affect the way dyes penetrate the 3D printed parts;

- What if the colour fades when exposed to UV light and heat?

- So far, we are yet to see a source that confirms that the textile dye used for pot dyeing is effectively appropriate for 3D printed parts. We haven't seen any ISO certification yet that guarantees the safety of operators who use this process.

With a key focus on automated processes that have been certified by EU and US standards, this article aims to **shed light on the different AM technologies** where it can be leveraged, to describe the **dyeing step of the post-processing stage**, as well as a **few examples of applications** in the industry.

## What AM technolog(y/ies) for dye colours?

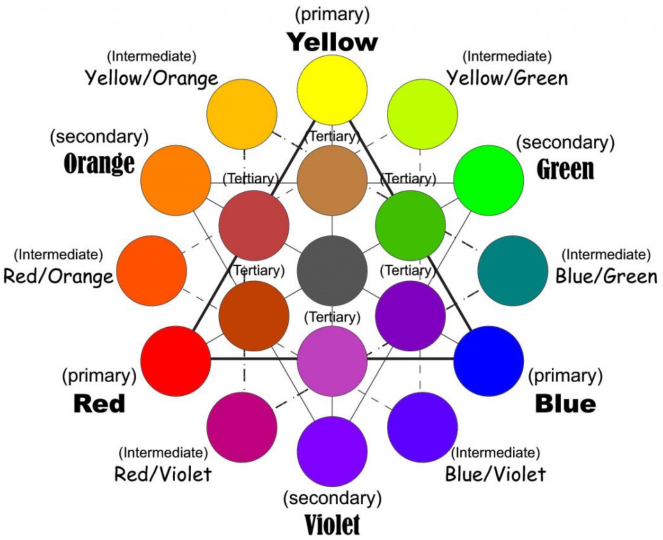
Depending on the AM process leveraged and on the manufacturing goal of a given part, some post-processing tasks may be favoured over others.

As far as dyeing is concerned, the colouring process has always been considered as mostly problematic for parts manufactured via a sintering process ***(Selective Laser Sintering, Powder bed fusion)***. That's why, 3D printed parts that have been produced via sintering are often mentioned as the main one that may require dyeing.

Associating dyeing exclusively to SLS can be explained by the fact that this manufacturing process is one of the most commonly used processes for industrial applications, namely for structural components. The other reason may be the fact that **dyes are usually confined to their aesthetical purpose** or their ability to **enhance the objects' resolution**, while recent developments in the field reveal that they **might also confer functional properties** to 3D printed components.

*"Modifying elastic moduli upon light irradiation, inducing optical and emitting properties in the matrices or conferring temperature responsivity are just few examples of innovative stimuli-responsive materials that can be produced by combining well-designed dyes with the appropriate 3DP printed matrices"*, a research on "Functional Dyes in Polymeric 3D Printing" reads.

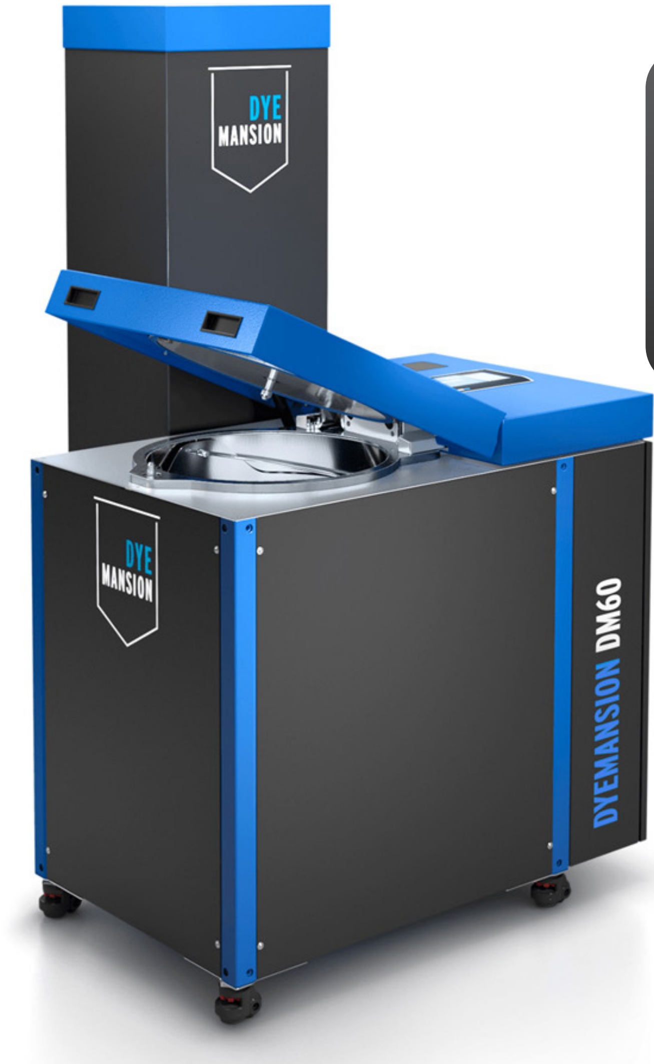
In this vein, **dyes can deliver specific properties** such as modification of mechanical behaviour, light emission, tunable permeability, controlled wettability or mechanochromic features depending on how they are utilized with **photopolymerization techniques (SLA, DLP), Direct Ink Writing, SLS or FFF**. To achieve such properties, dyes are generally used during the printing process which means that, with this method, they cannot be considered as a step of the post-processing stage.




Mixing colors examples – Image via 3D Systems

As for the main goal of this article, which is to explore the direct colouring process of 3D printed parts after they come out of the 3D printing machine, one notes that companies that have been investing extra miles to automate this process include for instance, **DyeMansion**, **CIPRES GmbH** and **Girbau**. Moreover, although they are known for their ultrasonic cleaners, it should be noted that **OmegaSonics** has developed a dye tank specifically to dye parts from HP MJF's technology or Stratasys' technology.

**DyeMansion**, the youngest one in this list, was founded in 2013 and started its activities as Trindo, a 3D-printing agency that sold 3D-printed smartphone covers in the corporate design of large companies. In 2015, when the team developed their first industrial colouring solution – ending the smartphone journey –, Trindo became DyeMansion and since then, has been dedicating its core business to post-processing solutions of 3D printed parts.




DYEMANSION DM60 – Coloring solution for industrial AM. Image via DyeMansion.

Legend: 3D Printed bearing, threaded screw and mesh assembly Center, Rigid Clear M2R-CL, M2G-CL Armor and M2G-DUR ProFlex; Outer ring, M2R-CL dyed with 1% concentration (60C and 30min) – Image via 3D Systems.

In 2004 when it was founded, **CIPRES** was a manufacturer of laser sintering prototypes. In 2006, the company has decided to deliver serial production of 3D printed parts, and since then, has also been focusing its activities on the development of colour techniques, colour units and solutions for surface finishing.

Image: Courtesy of CIRPES GmbH – Colouring unit

**Girbau** is the company that raises our interest the most in this short list. Very little communication is done about its 3D printing activities. The company is acknowledged for the manufacture and sales of industrial laundry equipment as well as its expertise in water management and temperature control. Headquartered in Vic, Spain, the company was founded in 1960, and is still managed by the **Girbau family**. With an annual turnover of €185 million, Girbau employs over 1 000 staff today, holds 15 subsidiaries across the world and is backed by 80 resellers.


An exchange with **José Maria Maristany**, responsible for the Girbau program in the AM industry, enabled us to discover that the company started developing a dyeing solution for AM in 2018, thanks to a partnership project between **Girbau lab** (Girbau open innovation platform) and **Hewlett Packard** (HP).

The project gave life to **DY130**, primarily intended for HP Jet Fusion 3D 4210/4200 Printing Solutions, an only dyeing solution dedicated to AM *in the company's portfolio. "We have decided to focus on dyeing solution because of the synergies between Girbau traditional know-how in [water management and temperature control]. We are currently working on adjacent products and services to complete our dyeing solution and enhance our value proposition"*, **Maristany** told 3D ADEPT Media.

## The automated dyeing step of the post-processing stage

As often mentioned in our dossiers, the post-processing stage is a long phase that comprises many different tasks that operators can perform to deliver the desired end-product.

If you are familiar with 3D printing production, then you probably know that the first step in the 3D printing post-processing workflow is **cleaning**. It appears right after the part has been cooled and **uncaked**. This stage remains of paramount importance prior to performing dyeing to avoid stains that could be left by white powder and to obtain a very functional part.

(Nonetheless, if some stains do appear after the dyeing process, then a bead blast or shot peening post-process step is required. A shot peening after the dyeing process might help to improve the aesthetic appearance of the parts.)

So, normally, right after the cleaning phase, the dyeing process is relatively simple to achieve and consists of two main phases. *"In the first phase, parts are immersed into a dyeing bath with specific temperature conditions for a prescribed period of time. In the second phase, [the operator] rinses parts with water"*, Maristany explains.

Printing → Cooling and uncaking → Cleaning → Dyeing → Drying

Production workflow

| | Production workflow | | | | Process |
|---|---|---|---|---|---|
| | Place into laundry bags | Dyeing process | Drying | Sandblasting / shot peening (optional) | Prepare dyeing solution |
| Operation time | 5 min/batch | 0 min/bath | 10 min/batch | 30 sec-5 min per piece | 5 min/per 5 batch |
| Process time | 5 min/batch | 2.5 hr/batch* | 2-3 hr/batch | 30 sec-5 min per piece | 40 min/per 5 batch |

* If there is a hot water supply installation, the process times shown here will be faster, reducing the processing time to approximately 45 minutes. Source: **Girbau**.

The teams of Girbau and HP that have worked on the development of the Girbau **DY130** explained in a report that, to achieve colour uniformity for parts through this process, all details and cavities of the parts are reached. Not only is the process repeatable, but the operator is not limited by the size of a small pot as it is the case with pot dyeing. Therefore, many parts can by dyed at the same time.

However, two main recommendations are worth noting:

The first one is that *"to avoid the physical marks produced by movement of the pieces during the drying process, the use of laundry bags to separate pieces (with different weights) in the same batch is strongly recommended. And, "as the process takes place in water, it is important to keep in mind that, as parts absorb some water during the process, their dimensional and mechanical properties may change slightly. Warpage of thin and flexible parts could be affected."*

A closer look at the DY130 dyeing solution from Girbau reveals that the solution's predefined programs include **Dye bath mixing, Dye bath conditioning, Dyeing 60° C, Dye bath disposal and Cleaning.**

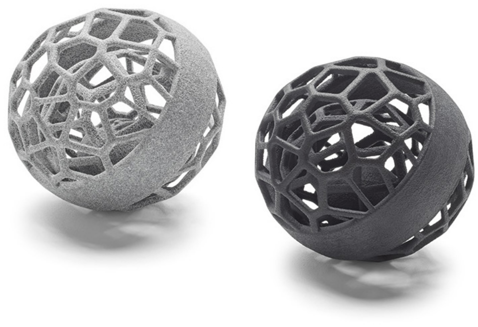
Speaking of materials their solution can process, Girbau's expert states that *"HP has validated [their] solution for PA11 and PA12 materials. DY130 could be used to dye parts produced with similar Industrial 3D printing solutions such as SLS."* Although the information has not been confirmed yet, the solution could also be compatible with the recently launched Stratasys SAF technology.

Lastly, operators might need a dedicated machine by colour, but colour change remains feasible using recommended detergent and some operational activities.

### Applications and Outlooks

Dyeing for 3D printed parts has proven its relevance in applications where a pleasant look is crucial. Consumer products like eyewear, watches, or figurines, some medical parts used for training, as well as some automotive and industrial parts are a few examples of applications that may require this (optional) process of the post-processing stage.

Although automated dyeing seems to present a lot of advantages, operators should always be careful when it comes to using it for parts that require a long-term contact with skin. Lastly, those who were used to conventional pot dyeing often depict the fact that with such technological advances, some human touch is lost. Whether it is true or not, in the end, they should not forget that it's up to them to decide whether they want to go for an automated dyeing process or continue with a traditional pot dyeing process.



3D printed parts produced on MJF – Coloured by Girbau – Courtesy of Girbau

# COUNTRY FOCUS: THE NETHERLANDS

## Is the Netherlands the hub of Construction 3D Printing?

*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 focuses on “The Netherlands”. As a reminder, the January/February issue of 3D ADEPT Mag portrayed a state of the art of the Additive Manufacturing market in that country whereas the March/April Issue of 3D ADEPT Mag discussed the current reality of «printed electronics for automotive applications». The present article highlights five things you should know about construction 3D printing in The Netherlands.*

In the state of the art of the 3D printing market in the Netherlands, researches revealed that before the creation of 3D printing companies across the country, the kingdom first saw consumer-oriented companies trying to achieve some applications with 3D printing as well as a key focus on construction 3D printing. The truth is, first attempts to build with concrete 3D printing appeared in the mid-nineties at Weber Beamix' facility but the market was simply not ready for it; for a commercialization purpose.

Over time, organizations and companies around the world started to explore the possibilities offered by construction 3D printing, which has not gone unnoticed by Dutch leaders in the field. In order to stay competitive, a group of these giants which include Ballast Nedam, BAM, Bekaert, Concrete Valley, CRH, CyBe, SGS Intron, Verhoeven Timmerfabriek Nederland, Weber Beamix, Van Wijnen, Witteveen+Bos and stichting SKKB decided to join forces to create a pavilion that will feature a massive robotic concrete 3D printer at **Eindhoven University of Technology** (TU/e). That was in 2015. Since then, these companies backed by the Government and universities set the goal to make the Netherlands the leaders in construction 3D printing.

Today, several companies, aware of the potential of 3D printing for the architecture and construction industry have emerged. When we look at the Dutch 3D printing market today, we can't help but ask ourselves if construction 3D printing is not becoming a key differentiator that enables the country to stand out in the global 3D printing market.

**Here are 5 things we have noticed about construction 3D printing in the Netherlands that we did not see in other European countries (yet).**

### 1- Eindhoven is hosting the first European industrial 3D concrete printing facility

Two years ago, a group of partners that include **Saint-Gobain Weber Beamix, BAM Infra, Bekaert, Witteveen+Bos, Eindhoven University of Technology and Van Wijnen** decided to join forces to open the first industrial 3D concrete printing facility in Europe. As you can see, some of these companies were involved in the “pavilion project” at TU/e.

The 3D printing house factory was located in Eindhoven, a city considered as the “tech capital” of the county. For the partners, this “commercial industrial location for 3D printing concrete components for construction” is meant to serve as a place of research, a place where they can 3D print in a commercially sustainable way, and a starting point for numerous projects including the ***“Project Milestone”*** that you will see below.

During last year's last quarter, another Dutch company, **Vertico**, opened its 3D concrete printing facility in the city. What makes Vertico outstanding is its focus on fine detailing and architectural applications, as opposed to the more thickset printing application in larger structures.

Image: Vertico – Facility in Eindhoven

## 2- "Project Milestone"

In this industry, you know companies are really backing words with actions when you see their promises come to fruition. And when they deliver, it is not only a milestone for them, it's an illustration/example of what technology can do for a specific vertical industry.

In 2018, one year before announcing the opening of the 3D printing factory, the project Milestone was announced. Its goal? 3D printing five houses that will be rented in Eindhoven. At the heart of the project, one can find **Eindhoven University of Technology,** contractor **Van Wijnen**, **Vesteda** (real estate manager), **Saint Gobain Weber Beamix** (materials company) and **Witteveen+Bos**, an engineering company. Vesteda, the buyer of these houses, will rent them to those who will be interested. The architects **Houben & Van Mierl**o designed the project and were inspired by "erratic blocks in a green landscape".

On April 30th 2021, the partners announced the completion of one of the first 3D printed houses. The first tenants, a Dutch couple, received the key and are currently experiencing life in this newly constructed home.

*Image : 3DPrintedHouse*

## 3 - The Bridge Project

Another project that is currently taking shape in the Netherlands and that is worth mentioning is the **Bridge Project**. Presented for the first time at the "Innovatie Day" at RWS on October 2018, it is an initiative of **Rijkswaterstaat, the Netherlands** and **Studio Michiel van der Kley** in collaboration with the **Technical University Eindhoven**. It consists in applying new concrete 3D printing techniques in the building environment.

The original idea was to print a tunnel and **Nijmegen** had been chosen for the construction. The idea was quite timely as the city – located in the East of the country – wanted to build something eye catching and iconic after its nomination as the Green Capital of Europe in 2018. However, when the partners found the exact location of the construction, *"it became clear that a tunnel wouldn't be that easy, a bridge however would be very welcome"*.

In April 2021, more pictures have been shared by the partners of the project. It is not over yet, but what they have built until now is already 29.5 meter long. Until now, the longest 3D printed concrete bridge that has been certified by the **Guinness World Records** has been built in China and is 26.3 meter long. We are just at the printing phase of the "Bridge Project" and it has already beaten this record.

*Image via Bridge Project*

## 4- The biggest number of construction 3D printing companies in Europe – and probably in the world

The current list of companies that are pioneering 3D printed houses & automated construction is exhaustive. Between those that were born during the pandemic and those that went bankrupt, our latest research shows that the Netherlands is currently home to the largest number of 3D printing companies that focus partially or entirely on construction.

The country is currently hosting **10 companies** that are paving the way for sustainable construction using 3D printing: **Twente Additive Manufacting, CyBe Construction, Vertico, BAM and Weber Beamix, Coastruction, CONCR3DE, Rohaco, DUS Architects, MX3D** and **Aectual**.

**5- The "current economic climate" looks good for the construction sector**

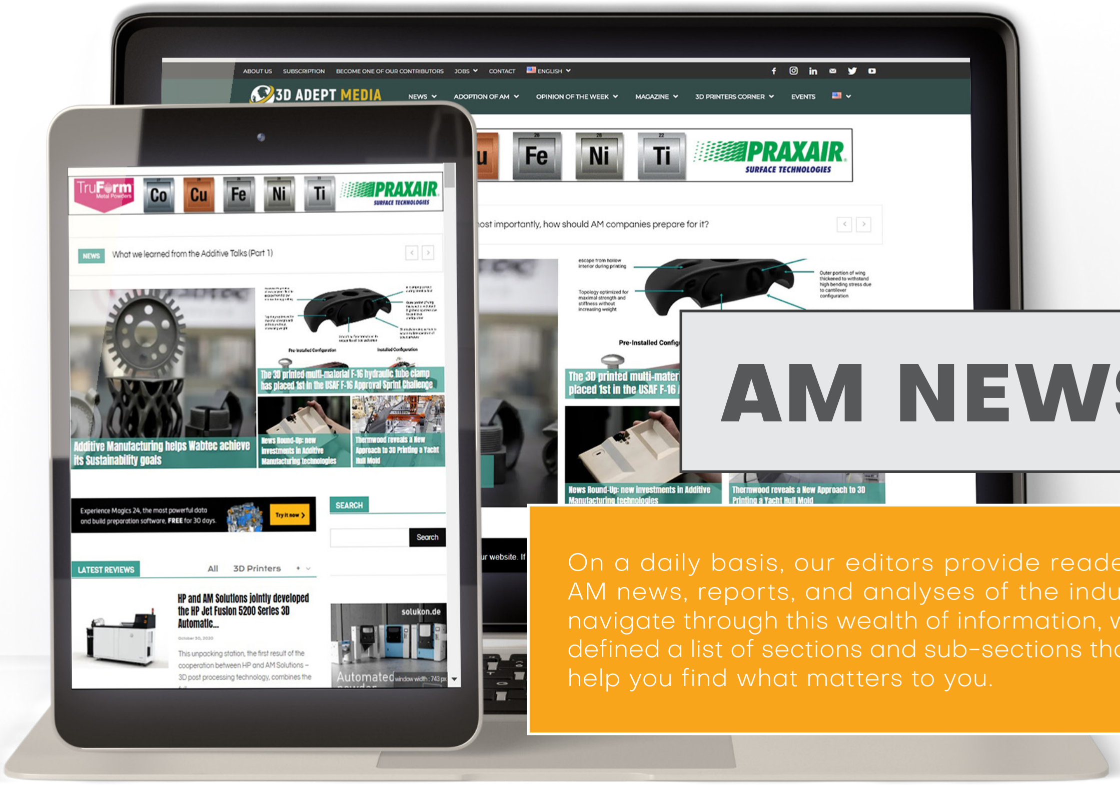
Well, it's a little bit hard to look at the construction 3D printing without any glance at the "general state of the construction sector in a given region".

We did not dive into the legal framework and related jurisdiction – we will let you that part of the work –; but according to **Lexology**, a comprehensive source of international legal updates, analysis and insights, *"the current economic climate has been good for the construction sector. Interesting trends include the redevelopment of existing buildings, sustainability/circularity and innovation. The demand for housing, logistics and data centres and flexible office concepts is also high and investors have shown an appetite for forward-funded projects. Further, new tax rules will likely lead to different ways of structuring projects, which will affect the number of entities used, financing and the moment of legal transfer"*. You may find out more about the legal framework on their article dedicated to construction in the Netherlands.

Based on these five points, can we legitimately say that the construction 3D printing industry in Europe advances at a good pace and the Netherlands is definitely one of the countries making history?

Image: CyBe Construction

Image: Agoria




# 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 matters 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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# SPORTING WITH ADDITIVE MANUFACTURING

*There are about 8,000 indigenous sports and sporting games. In this list, over 800 sports are currently said to be played around the world on a regular basis and about 200 sports are recognized sports with national and international federations. However, AM technologies have already played a key role for only 12 disciplines out of these 200. What are these AM applications? What are the AM technologies that enable them? What challenges and possible solutions may help sport companies – and eventually providers of AM technologies – move forward?*

***"Making sport better"*** has been the direct or indirect credo for most professionals working or aspiring to work in the sport industry, and this, regardless of the sport activity. For professionals who are on this mission, a means to an end has often been to rely on the capabilities of technologies; and trust me, there are a lot. One of the first technology solutions for the sport industry has been invented in the 1950s, a tracking race time. Over time, several technology solutions designed to improve performance in a wide range of disciplines have emerged and despite the fact that Additive Manufacturing has been invented in the 1900s, the first applications that show the potential of this technology for the sport industry popped up in 2010 and there were first of all motor sports applications followed by footwear.

Since then, additive manufacturing companies & professionals, together with sport companies but also researchers continue to explore what was possible to achieve with this technology in various fields of the sport industry.

As time goes by, a wide range of applications are revealed, for various technologies, but a recent discussion with a sports and technology fan raises some questions about the challenges all stakeholders might encounter when it comes to adopting AM in sports.

This discussion is of paramount importance now, as the current market still faces a low integration of AM in sports research. In **Erika Berg's** opinion, Managing Director of Business Development at **Carbon**, the reason for this might be that "*sports research has been widely focused on collecting data to understand performance, responsiveness and abilities of athletes. Additive Manufacturing has commonly been used for prototyping representative (not final) parts and low production runs, while lacking in the software integration and digital design tools that are required to create or modify parts based on empirical research data-- until now.*"

This article aims to shed light on some industry applications that have been made possible using AM technologies, reveal the main AM technologies used in the field and discuss the challenges for sports companies and manufacturers (or engineers) exploring the use of AM for better sport applications.

**What Additive Manufacturing applications for which sport discipline?**

There are about 8,000 indigenous sports and sporting games. In this list, over 800 sports are currently played around the world on a regular basis and about 200 sports are recognized sports with national and international federations. In this short list of 200 recognized sports, additive manufacturing technologies have already played a key role in 12 disciplines.

AM technologies encompass everything that ranges from the design to the post-processing stage of manufacturing. Although all of these disciplines require the use of industrial or professional 3D printers for their applications, it's fair to note that engineering teams behind each of these applications may have also used dedicated software tools, and other equipment necessary to achieve the end-use product.

| Disciplines | Applications |
|---|---|
| 1. Running/walking | 3D printed insoles, midsoles and footwear |
| 2. Cycling | Saddles, bikes' frames & mounts |
| 3. Badminton | Racket |
| 4. Motor sports | Racing cars or motors, engines |
| 5. Hockey | Helmet and **apparels** |
| 6. Skiing | Goggles, helmet or snowboards |
| 7. Golf | **Golf club** and block tee markers |
| 8. Surfing | Surfboard |
| 9. Ballet | Pair of ballerines; **apparel** |
| 10. Water sports such as sailing | Underwater scooter, key components of boats, and goggles |
| 11. Combat sports such as boxing | Mouthguard or shin guards |
| 12. Football | Footwear or shin guards |

3D printed saddle produced by Carbon. Image: Courtesy of Carbon

Riddell Helmet – produced using Carbon's DLS technology – Courtesy of Carbon

Puma project – 3D printed midsoles – Image: Courtesy of Nolan KIM

3D printed ballet shoes Image: Hadar Neeman

Interestingly, **James Novak** and **Andrew R. Novak**, researchers from Deakin University and the University of Technology Sydney in Australia, have published a study entitled *"is AM improving performance in Sports?"* in the Journal of Sports Engineering and Technology. Together, they have identified twelve sports where AM has already proven to play a key role.

In their abstract, both researchers explain that sport is an industry that may benefit from the opportunities offered by additive manufacturing (AM) and they recognize the important role of media in portraying the increasing adoption of the technology in sports products.

Although we can't confirm if the twelve sports we have identified in the paragraph above are the same the researchers identified, it's interesting to note that across literature, the running/walking field is the field that saw the biggest number of AM applications, followed by cycling and badminton.

However, based on our media coverage on AM applications in the sports industry, we came to realize that motor sports remain the field that delivers AM applications the most, followed by running/walking, as well as cycling.

Those contrasting portrayals of AM within sports can be understandable given the fact that the researchers' analysis and review took place across four different databases, and *"according to the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) 2015."* Furthermore, their results were confined to research and articles published between January 1984 and May 2019, exclusively written in English whereas our research covered AM applications until the present day.

Nevertheless, our questions remain the same. Sport may be a key vertical industry that might see an increasing adoption of AM technologies but **what are the AM technologies that may enable applications in these disciplines**? Most importantly, **what are the key performance indicators one should take into account to assess the capabilities of AM technologies in these disciplines?**

## What Additive Manufacturing technologies for which application?

From a technological standpoint, researchers and media coverages often lay emphasis on the impact of **3D scanning technologies, design software tools** and **3D printers** to achieve the desired applications. We rarely saw the type of post-processing equipment mentioned although we believe they also a play a big part in achieving the final product.

As far as 3D printers are concerned, one notes a blatant use of powder-bed fusion technologies such as selective laser sintering (SLS) or selective laser melting (SLM), FFF 3D printing as it is the case with hockey's apparels from Athletic Knit or mouthguards, as well as liquid-based technologies such as Carbon's **Digital Light Synthesis™**.

Carbon's **Digital Light Synthesis™** has been at the heart of several sport products including several adidas shoes (midsoles are 3D printed for the adidas shoes), Specialized® 's bike saddles, or the NHL Certified 3D printed hockey helmet liner. In a nutshell, the company's technology can deliver *"end-use sport products [that] incorporate the advancements in technology with data-driven designs."*

According to **Erika Berg**, Managing Director of Business Development at Carbon, the company's Digital Light Synthesis™ aka Carbon DLS™ uses *"digital light projection, oxygen permeable optics, and programmable liquid resins to produce parts with exceptional mechanical properties, resolution, and surface finish. Carbon DLS™ technology allows engineers and designers to iterate faster, deliver projects with less risk, and radically reimagine their products by consolidating parts, reducing weight, introducing impossible geometries or custom scanned products at scale."*

Erika Berg - Managing Director of Business Development at Carbon

For this technology to be effective, Berg said it needs to be combined with dedicated solutions which include materials, and design software.

No matter what AM technologies are used, the first thing to know is probably **how one can identify an AM application in a sport discipline**. Needless to say, identifying where and when AM can play a key role often varies from one expert to another, and from one industry to another.

Sometimes, the identification of such applications starts at the **research level**, as we saw with **Nolan Kim**, Application Engineer at Desktop Metal, who focused his thesis project on the enhancement of running performance through 3D printed lattice design.

A big part of Kim's work has been dedicated to **midsole**, a thick section of foam between the insole and the outsole. This part often raises a lot of interest within running performance research.

Indeed, *"just as the hips play a critical role in transferring energy between the upper and lower halves of our body, the midsole mediates the energy and forces produced between each running step. Its large volume in relation to the rest of the shoe creates an inviting space for implementing responsive technology and heightens the impact of a material's mechanical properties"*, Kim explains.

*"Before 3D printing, the nature of injection moulding prohibited the intervention of any internal modifications — control was limited to the outer perimeter of the midsole and thus much of the performance benefits were heavily dependent on just the foam material itself. Now with additive technology, the internal anatomy of the midsole can be viewed as a void to be filled with linkages of highly variant geometric structures that can offer beneficial features such as high energy return and stability. When surveying recent developments, all disruptive innovation within the running footwear space has come from embedded components such as carbon fiber plates, air bags, and tensile strands. This narrative unquestionably beckons the use of additive methodologies whose very purpose lies in unbound design freedom and unmatched structural controllability. The capacity for advancement is expanded with greater fluidity in the design's construction"*, he adds.

On the other hand, from an OEM perspective, technologies are continuously assessed by in-house experts in order to discover how they can deliver the best products possible. A conversation with **Mike Yagley**, VP of Innovation and AI at **COBRA Golf**, golf club and golf equipment manufacturer revealed that before they turn to AM technologies, **investment castings** and **forging** are usually the primary conventional manufacturing processes that are considered for the fabrication of golf clubs.

Here is the thing, for a relatively simple object which is made up of a head, a shaft and a grip, the manufacturing process is far from simple.

*"The clubhead alone requires about 400 people to be effectively completed."* ***Taking the example of the clubhead alone, he adds:*** *"the fact is, what happened to the piece of metal after castings does get complicated as it requires many processes before obtaining the final product: grinding, polishing, finishing, cutting grooves, handwork, sometimes chrome or painting,* [to name a few of the tasks]. *Some clubheads that are manufactured using carbon fiber for instance, require a lot of handwork.... The process of preparing the surface and putting up the blue is a manual process. The shape of the head is very complex, there are not flat surfaces which means it is very difficult to automate that process or even the post-processing stage of the manufacturing."*

Therefore, in order to cut down the product development cycle, the COBRA team decided to turn to AM, and in this journey, they decided to rely on **HP Multi-Jet Fusion**.

Mike Yagley, VP of Innovation and AI at COBRA Golf

### *Challenges sport companies may encounter when using AM technologies: the case of COBRA Golf*

When you have decided that AM is the path you want to follow in your manufacturing journey, the next step might be quite intimidating. Indeed, for a niche market like AM, finding 12 sport disciplines where AM can potentially disrupt the market is a good start but it is not enough.

A difference should be made between applications that result of a one-time collaboration to explore some technologies, or for ad hoc actions, and applications that may lead to commercial developments. In the end, it is the latter argument that counts the most and makes OEMs ask themselves: **"given the purpose fast-changing customer demands and rising requirements in product performance, how can I improve my products to stay competitive?"**

*"As improvements can be seen in each iteration and endless trade-offs can be studied through digital simulations, it can be challenging for customers to know when to lock a design and commercialize a product. There is a balance to take into consideration when setting a new standard or level of performance in a respective market while establishing precedence and gaining a market advantage as the first mover"*, Carbon's **Erika Berg states**.

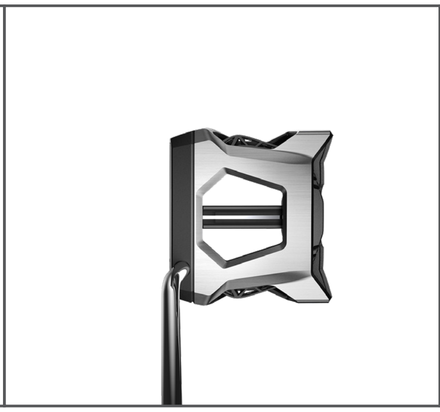
In the case of COBRA Golf for instance, **Yagley** told us they needed to manufacture a viable product but also to implement a process; and only thereafter, see if and how it was possible to deliver a collection of 3D printed products that could be commercialized.

That's the reason why 2020 first saw a putter with a 3D printed head fabricated using HP Metal Jet technology. This product helped them truly assess the capabilities of the technology, and what they would like to improve. According to the expert, what makes a key difference with what they used to do with conventional manufacturing processes alone, is the post-processing stage. This time, *"the surfaces of the 3D printed head are CNC machined to apply the final cosmetic finishing, and ensure the most accurate functional product."*

Furthermore, at the design level, the number of design iterations that the Cobra team can achieve via AM is significantly less than iterations that can be achieved via conventional manufacturing processes. The final design of a part for instance, may require about 50 iterations that could be achieved during a one-year period whereas using castings and forging as they used to do, the team could spend several years on a single design.

Nevertheless, the lessons learned from this product development cycle and process implementation – including the fact that not all components can be manufactured via traditional processes – help the Cobra team envision a collection of 3D printed products. As a matter of fact, on May 2021, the OEM has officially entered the putter market today, with the **KING 3D Printed Series, its first complete line of 3D Printed multi-material putters.**

AGERA Model – Face – Courtesy of Cobra PUMA GOLF



AGERA Model – Putter – Courtesy of Cobra PUMA GOLF

AGERA Model – Back – Courtesy of Cobra PUMA GOLF

### *What KPI (Key performance indicators) should we take into account to analyse the performance of a 3D printed product?*

The last assessment anyone who leverages AM technologies will perform, will consist in determining if AM was a better production candidate as compared to conventional manufacturing processes. The questions OEM will try to answer here are: **do I have a better, functional and aesthetic product when I use AM and how do I know that?**

*"Performance can be dependent on weight, amount of ventilation, safety, or a fine-tuned structural response to increase energy return or dissipate rotational forces. The sport disciplines and desired performance outcomes are based on years of athlete data, consumer profiles and target metrics set by each OEM's product team.*

*Improvements are measured in many different aspects of the product, depending on the sport discipline and design requirements. We have seen magnitudes of percentage improvements unlocked for energy damping or energy return in lattice applications, which replace foam or multiple layers of foam in a part. Customers have used wind tunnels to test aerodynamic performance and quantify heat reduction, acoustic chambers to measure and fine-tune desired frequencies of impacts, and extreme wear tests for material durability and UV stability, where DLS has met or exceeded product requirements of the incumbent materials made with traditional manufacturing methods"* Carbon's expert emphasizes.

Speaking of lattice applications, in the golf industry, the manufacturing stage of COBRA Gold's line of 3D Printed multi-material putters required the combination of HP's proprietary 3D Printing Technology with SIK Golf's **patented Descending Loft Technology** (DLT). The latter integrates four descending lofts on the face to fabricate a consistent launch angle and roll for different putting styles and stroke consistencies. In other terms, SIK's DLT helps to achieve **weight savings and soft, yet crisp feel at impac**t.

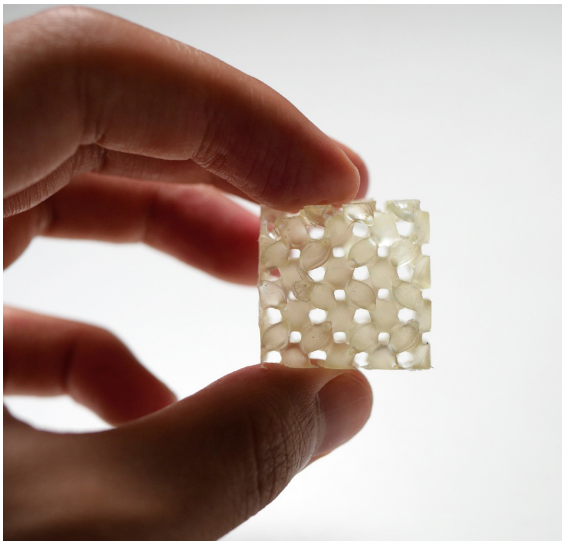
As far as AM is concerned, this collection highlights the **intricate 3D printed lattice cartridges** as a key component that required the use of AM. The cartridges are pivotal to creating discretionary weight and achieving the highest MOI possible in each putter model, which in this case, is the most tangible KPI to examine in order to appreciate the potential of AM.

*(MOI stands for "moment of inertia." This measurement (grams per centimeter squared) shows how much resistance a clubhead has to twisting.)*

Apart from weight optimization, the lattice cartridge also acts as a supporting structure to the body and damps vibrations and fine tunes sound. The 3D printed lattice structure therefore delivers a **high MOI design for enhanced stability and roll performance in three distinct models – The GrandSport-35** (OS Blade), **SuperNova** (OS Fang), and the **Agera** (OS Mallet). The company reveals that each model features a steel chassis, a forged aluminium crown, tungsten weights, and a SIK Face Insert to deliver unmatched stability and roll consistency on every putt.

While no figure has been given for this latest collection, we learned that for the previous product, the design has enabled a larger distribution of the head's weight to its perimeter, augmenting this way, the club's MOI 20% over a comparable shape achieved traditionally; this might lead to improved consistency in putting when the golfer will be using the club.

Let's take the example of **midsoles in the footwear industry**. In this specific case, the **shoe weight** and the **energy distribution** during the activity are two of the KPI that will be assessed here to determine if AM was a good option.



UnitCell – Courtesy of Nolan KIM

*"It is important to recognize that printed material will never behave exactly as injected foam. An attempt to mimic every intrinsic characteristic of foam within a printed model is a futile and misguided approach. Rather, it would be worthwhile to pinpoint certain properties and outcomes that hold the most importance in relation to the particular performance goal. For instance, it seems to me that perhaps the most potent drivers of running performance are weight and energy return. To be specific, every 100g of reduced shoe weight has shown to improve marathon finish time by about 1% and the more energy returned to the runner subsequently lightens the physiological expenditure amassed when maintaining an intense running pace"*, Kim points out.

## Areas for improvements and opportunities for the future

Moving forward, there is no doubt, the number of sport disciplines that might leverage additive manufacturing will increase with dedication and continuous collaboration between OEMs and AM experts.

Right now, with the current applications available, OEMs like COBRA Golf recognize that despite the great capabilities of AM and its ability to deliver a functional and better product, the cost of the final product remains quite expensive.

**Yagley** believes that this is certainly due to the fact that the exact AM materials for some applications are still lacking. This may explain why the cost of the final end-product remains a little bit expensive compared to the product that has been mass-fabricated. Nonetheless, he remains confident that, over time, as technology matures, the price of the 3D printed final product will be accessible to more end-consumers.

Kim's point of view on costs nuances Yagley's opinion on costs a little bit by refocusing the debate on the "rapid improvements" of AM technologies. Although he recognizes that AM is often a costly production method, he thinks that the hesitation to adopt additive technology may be less due to actual disadvantages and more so a lack of proper information.

Nolan KIM

Kim's point of view on costs nuances Yagley's opinion on costs a little bit by refocusing the debate on the "rapid improvements" of AM technologies. Although he recognizes that AM is often a costly production method, he thinks that the hesitation to adopt additive technology may be less due to actual disadvantages and more so a lack of proper information.

As far as the footwear industry is concerned, he learned that, *"the most intriguing observation is the ability to construct highly complex parts at a lower cost than traditional processes. Justifiably, the concern of adopting additive methodologies is that the cost of producing an individual part is always the same, no matter if there are five or a thousand models made, whereas for traditional methods the cost per unit decreases as the total number of manufactured units increase. However, this isn't the complete story for as the complexity of a part increases, there comes an inflection point where the manufacturing cost actually becomes comparatively cheaper for additive manufacturing. So now, not only does design complexity open up new avenues for innovation, it could also come at a lower cost."*

From a technological perspective, as Carbon's expert says, AM technologies help manufacturers envision the *"flexibility of manufacturing without the burden of retooling."* However, for OEMs who are not ready to invest in costly AM technologies, there is and there will always be the possibility to rely on AM service bureaus to fabricate products that improve comfort and performance levels.

As regards to processes, the industry still needs a focus on **materials** and **structures**, at least for midsole applications made possible using AM.

**Kim** lays emphasis on the need to formulate materials that are responsible, durable and lightweight. As for structures, he believes, that a wide range of possibilities are currently given to professionals. *"With the expansion of generative and algorithmic design tools, serious discussion of refined customization, personalization, and data-driven models have surfaced. Now, not only does there remain the unending search for the highest-performing structure, but also there lies the backdrop of systematically preparing these models in a way that can be seamlessly modulated to the unique demands and features of the user. All the while, the grandeur of these ambitions must, ideally, uphold the highest form of sustainable practice. There are many considerations to be conscious of and complications to be clarified, but the potential of additive design to outperform conventional foams surely exists and is only yet to be realized"*, he concludes.

In the short run, despite the focus of this article on AM, one should recognize that the opportunity to make better sport products and to a certain extent create new business models, may also depend on the interplay between AM and advancements in other fields like artificial intelligence, sensor technology, and robotics.

## About the contributors

***Nolan Kim*** *currently works at Desktop Metal as an Application Engineer for special projects. He graduated from Boston University two years ago with a major in Biomedical Engineering and focused his thesis project on the enhancement of running performance through 3D-printed lattice design. Since graduation, he has progressively become more invested in the realm of additive innovation and has no plans of setting his sights elsewhere. What he learned as part of his thesis project has been helpful in revealing what to expect from AM technologies when it comes to manufacturing midsoles for the footwear industry.*

*Founded in 1973,* ***Cobra Golf*** *is a golf club and golf equipment manufacturer. The company has been acquired by sportswear brand Puma since 2010. Puma Gold has been collaborating with HP for several years now, a collaboration that facilitates the company's utilization of AM technology and the recent release of the KING 3D Printed Series, its first complete line of 3D Printed multi-material putters. For such "applications" focus, it is pivotal to have point of view of OEMs who are already adopting AM technologies, in order to give a more neutral information to those who are looking to make their first steps in the field.*

*From premium bike saddles for elite road cycling to mass produced helmets purchased in retail stores, Carbon DLSTM technology allows athletes to push performance with better products. The 3D printing and digital manufacturer continuously partners with OEMs and global contract manufacturers to create better products in faster product development cycles, allowing athletes at all levels to improve their game.*

## Resources:


Hire Intelligence, the Evolution of Technology in Sport

Is additive manufacturing improving performance in Sports? A systematic review, The Journal of Sports Engineering and Technology.

Insights from Carbon, Nolan Kim & Cobra Golf

Media coverage on www.3dadept.com

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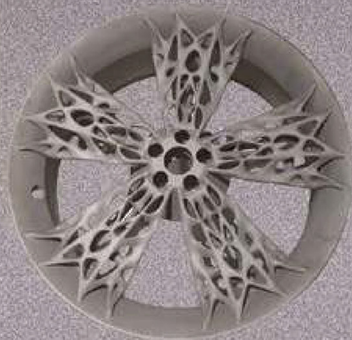

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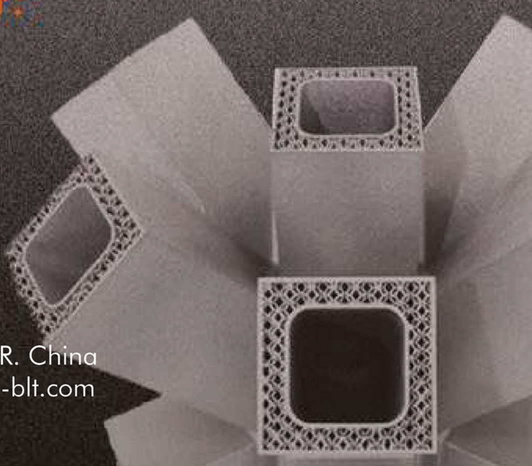

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Edited by 3D ADEPT MEDIA
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2022
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Published by 3D ADEPT Media