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3D ADEPT MAG

3D PRINTING

DOSSIER : UNDERSTANDING THE COMPLEXITIES AND OPPORTUNITIES OF MULTI-LASER ADDITIVE MANUFACTURING

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Tel : +32 (0)4 86 74 58 87

Email: contact@3dadept.com

Edited by 3D ADEPT Media

Graphic Designer

Charles Ernest K.

Editorial team

Kety S., Yosra K., Martial Y.

Proofreaders

Jeanne Geraldine N.N.

Advertising

Laura Depret – Laura.d@3dadept.com

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Questions and feedback:

3D ADEPT SPRL (3DA)

VAT: BE0681.599.796

Belgium –Rue Borrens 51 – 1050 Brussels

Phone: +32 (0)4 86 74 58 87

Email: contact@3dadept.com

Online: www.3dadept.com

Table of Contents

Editorial04

Dossier.....07

UNDERSTANDING THE COMPLEXITIES AND OPPORTUNITIES OF MULTI-LASER ADDITIVE MANUFACTURING

Business13

- THE INVESTMENT LANDSCAPE IS CHANGING. WHAT SHOULD FOUNDERS CONSIDER TO GROW THEIR AM BUSINESS ?

- BOOTSTRAPPING VS FUNDRAISING: HOW MAKELAB SUCCESSFULLY NAVIGATES A LABYRINTH OF UNCERTAINTIES.

Materials.....21

- (CRITICAL) CHALLENGES RAISED AND SOLVED BY HIGH-PERFORMANCE POLYMERS FOR AM – KEY EXAMPLES IN THE AUTOMOTIVE INDUSTRY.

- UNBOUNDING 3D PRINTING AT SCALE WITH NEW SUSTAINABLE MATERIALS

Post-processing31

UNDERSTANDING THE INFILTRATION AND COATING PROCESSES FOR ADDITIVE MANUFACTURED PARTS

Software35

IS AI THE “MAGIC WORD” DESIGNED TO MAKE YOUR PRODUCT DESIGN LESS BORING ?

Applications41

CAN CERAMIC AM ADD VALUE TO THE AUTOMOTIVE AND AEROSPACE INDUSTRIES? FROM R&D TO COMMERCIAL APPLICATIONS.

AM Shapers45

FROM TOOLING TO END-USE PARTS PRODUCTION: A LOOK AT THE STRATEGY THAT ENABLES GENERAL ATOMICS AERONAUTICAL SYSTEMS TO REACH BEYOND 75% OF 3D PRINTED PARTS IN AN AIRCRAFT.

Events51

- ADDITIVE MANUFACTURING FOR AEROSPACE, DEFENCE, & SPACE

- 35 YEARS OF AMUG: THE HOW AND THE WHY OF A VOLUNTEERING COMMITMENT THAT PUSHES THE AM INDUSTRY FORWARD

Hello & Welcome



Staying in touch with reality.

There were some great things to celebrate in 2022 and some lessons to be learned. Overall, I must admit that this year has left me with a sense of unfinished business when looking at the business model for entrepreneurs, and the current economic situation. I'll tell you right now: I have developed some form of admiration for people who create and imagine a product or a service that can improve the world. But let's face it: beyond their will and their mission, there is the reality of being a profitable and successful company.

So, I took an unofficial interest in them: I heard a lot of rumors, but for each entrepreneur I met, there was and still is a lot of hope, the hope of overcoming the financial challenges and uncertainties of their business.

My colleagues and I wanted to make this topic official. Whether it's the beginning of the year, the middle of the year, or the end of the year, I believe that talking about funding is a timeless topic and in this first issue of 3D ADEPT Mag for 2023, we devote some time to it and offer solutions for two categories of people: those who are in a bootstrapping model and those who are constantly looking for funds.

Finally, although money can remake the world (of AM) to some extent, it is still considered to be wasted without solid concepts and viable technologies. Therefore, we also decided to break the stereotypes, map out the current reality, and identify the areas of improvement for these technologies that are often described as miracle solutions to engineering problems. This issue thus discusses ceramic additive manufacturing, metal (and multi-laser) additive manufacturing, artificial intelligence, infiltration and coating processes, and high-performance materials - all with a focus on the automotive and aerospace industries.



Kety SINDZE

Managing Editor at 3D ADEPT Media

✉ ketys@3dadept.com

Editorial



Significant Cost Savings on Additive Tool

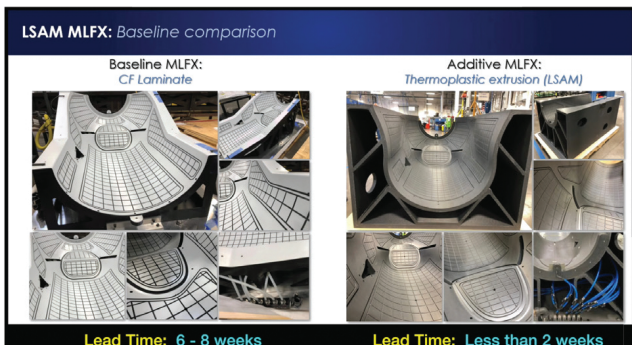
Partnership between Thermwood and General Atomics

The Details

Using a Thermwood LSAM 1020, the tool was printed from ABS (20% Carbon Fiber Filled) in 16 hours. The final part weighing 1,190 lbs was machined in 32 hours.

Cost Savings of around \$50,000 vs traditional methods

Total lead time for the part decreased from 6-8 weeks to less than 2 weeks by utilizing the powerful LSAM system.

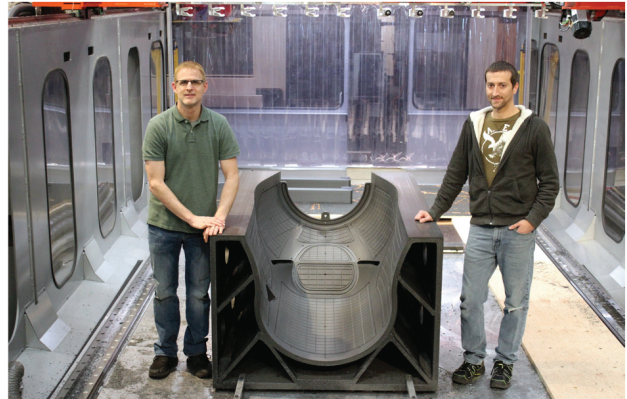


Scan QR code to view a video of the LSAM and General Atomics process.

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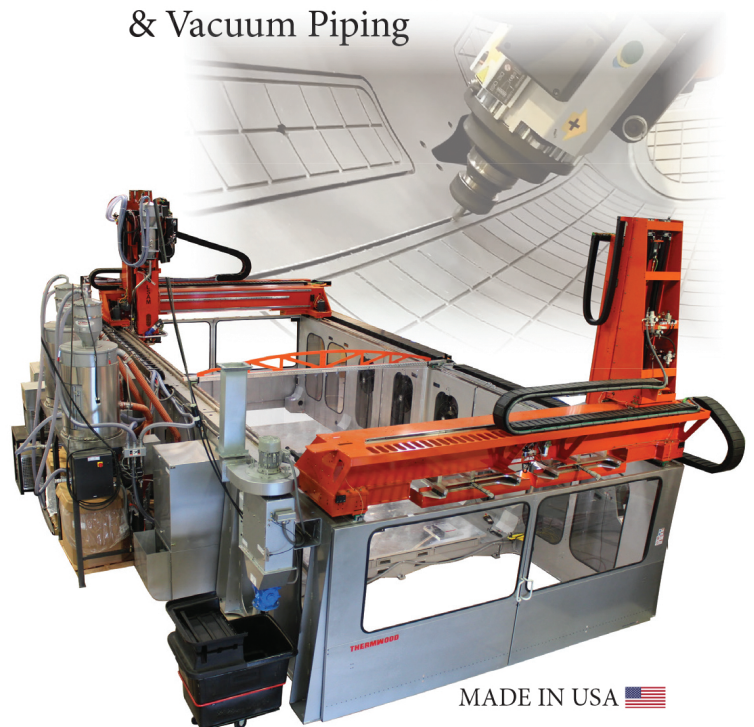
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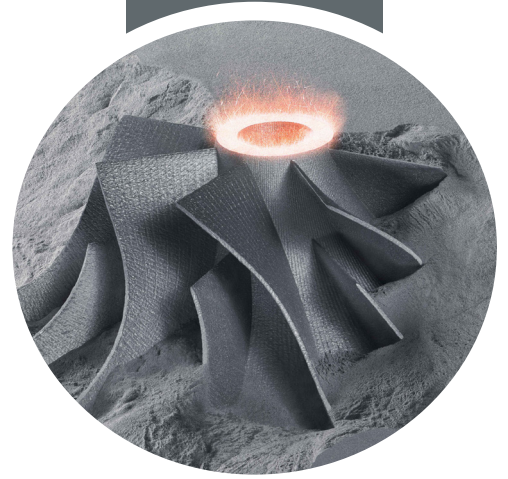
The Results

- Cost Reduction: 2-3 times
- Faster Development: 3-4 times
- Production Capable Tool
- Vacuum Integrity
- Suitable for Large, Deep 3D Geometries, Backup Structures & Vacuum Piping



MADE IN USA

Understanding the complexities and opportunities of Multi-Laser Additive Manufacturing



One thing fans of Star Wars and fans of laser games would likely agree with, is that lasers are super cool. Why? You could ask. Because of speed. More lasers mean more agility and more speed. In the AM industry, the possibility to have more lasers in an industrial 3D printer also seems cool to a bunch of users. But, does it necessarily mean more agility and more speed ?

Whether they are 2, 4 or 12, lasers remain the most effective energy source in a 3D printer since they can transfer a large amount of energy into micro-scale focal region instantaneously to solidify or cure materials in air, therefore enabling high-precision and high-throughput manufacturing for a wide range of materials. As AM increasingly embraces (mass) production, part manufacturers are eyeing the integration of multiple lasers within a 3D printer with great interest. To facilitate their decision-making process, it's important to understand why and how multi-laser AM machines make sense.

While the focus is usually (and will be) made on **powder-bed fusion processes** (as part of this dossier), it should be noted that AM processes that are based on **SLS, DED (Directed Energy Deposition)** and **VAT photopolymerisation** can also be equipped with multiple lasers.

"In polymer AM there is selective laser sintering (SLS) that is also available with more than one laser source. There are some stereolithography machines with multiple lasers as well, however the required energy density for photopolymerization is low, so there are other methods that expose more than one area at a time", **Dr. Ing. Dominik Schmid**, Sr. Engineer, at [Kennametal](#) comments.

According to Kartik Rao, Strategic Marketing Director at [Additive Industries](#), the industry that probably shows us a path where we are going to head down is the laser cladding industry. *"There are a lot of people that work with laser cladding in the oil and gas industries; so, they take big, long shafts*

and they are cladding the whole thing in wear-resistant materials with multiple robots working on a part. Ultimately, that's probably where AM is headed".

While each of the aforementioned technologies uses different types of laser and laser power and requires different beam sizes on the build plate, the ultimate goal for part producers is the same: **enhance productivity while eventually reducing the cost per part**. Here is the thing, a number of technical challenges may arise when working with multiple lasers in a powder-bed fusion process.

When does "more" mean "better"?

First of all, if you are looking to support R&D efforts or achieve prototypes, a single-laser 3D printer might remain your best option.

However, if you are looking to enhance the throughput of your 3D printer, or lower cost per part, there is a great chance that exploring multi-laser 3D printers is a great idea. For others, it often comes down to answering a couple of questions: how many parts can we achieve within a single batch – at one time? How large can a part be in the build envelope?

"Multi-laser systems have a higher build rate meaning the production capacity is higher compared to single-laser systems. On the other hand, they are more expensive than single laser systems. So, it is important to make usage of that additional capacity the systems provide. In short, the most vital factor in whether it makes sense to use multi laser systems is the demand for additive products", **Kennametal's** expert points out.

Emphasizing on the technical reasons why it makes sense to use multiple lasers in powder-bed fusion processes, Additive Industries' speaker notes:

"In the powder-bed area, it makes more sense to have multiple lasers because ultimately, you want as much of the powder bed to be active as possible. The cost of the part may be a reason worth considering as well as the size of the parts you will be able to build. Very large parts for instance may require to have multiple lasers working on them, otherwise it may take up to 30 days to build, which is clearly a very long time and it will not be scalable for your business. It also makes sense if you have smaller parts on a large build tray."

Rao's example on large parts comes from the fact that, in powder-bed fusion processes with multiple lasers, lasers are spatially separate to expand coverage or to enable the lasers to reach a larger area.

On another note, even if productivity is advocated, quality should also be part of the equation and that's something that can be challenging when one is aware of the implications surrounding **material properties**, **build strategies** and other **laser parameters** relevant to additive manufacturing.



Kartik Rao, Strategic Marketing Director at Additive Industries

Laser parameters relevant to multi-laser AM systems

It's legitimate to question the material properties of parts achieved with multi-laser AM systems – with the hope that they have the same properties achieved with single-laser systems. Most of the time, you might hear that multi-laser AM systems can achieve the same homogenous material properties in areas of the part as the ones delivered by single-laser AM systems. However, a couple of items that are inter-dependent should be considered.

Schmid explains that the scale with more laser sources is not linear. *"A machine with four lasers might only be three times as fast as a single laser machine because the recoating time basically remains the same. Whether it is possible to reduce manufacturing costs with multi-laser systems depends on the specific application as well as the required investment in the machines themselves. Multi-laser manufacturing brings additional challenges, such as laser alignment or more complex design of the inert gas flow, so the ideal result is when quality can be achieved equal to a single laser machine"*, he outlines.

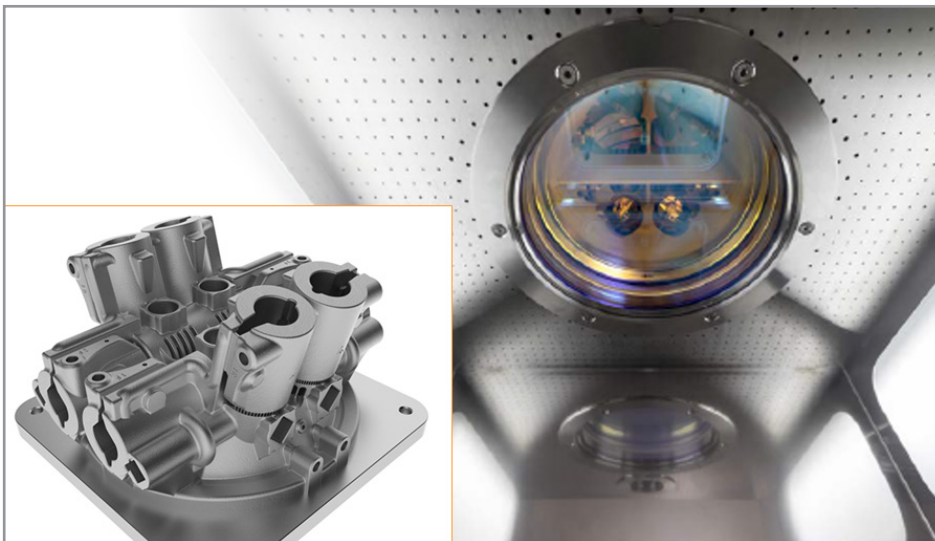


Image above – compact galvo mounting block with integral water cooling (inset left) allows four closely-spaced laser beams to enter the build chamber through a single optical window (main image). | Courtesy of RENISHAW

Rao completes this explanation by laying emphasis on the fact that, **more lasers necessarily do not necessarily mean faster production or quality production.** As a matter of fact, shops should take into account a number of issues that are likely to occur with multi-laser AM systems – quality issues caused by:

- zoning/stitching of parts
- interaction of lasers with condensate from another active laser
- gas flow (heat management and waste removal)
- calibration of lasers (absolute and relative)

Producing with multiple lasers can often lead to lots of spatter which is important to handle effectively. Indeed, when there is not enough space between several lasers, they might “stitch” on the part, thus giving unpredictable results. To address this issue, some machine manufacturers have developed systems with reasonable overlap coverage. This enables operators to assign lasers to build individual parts.

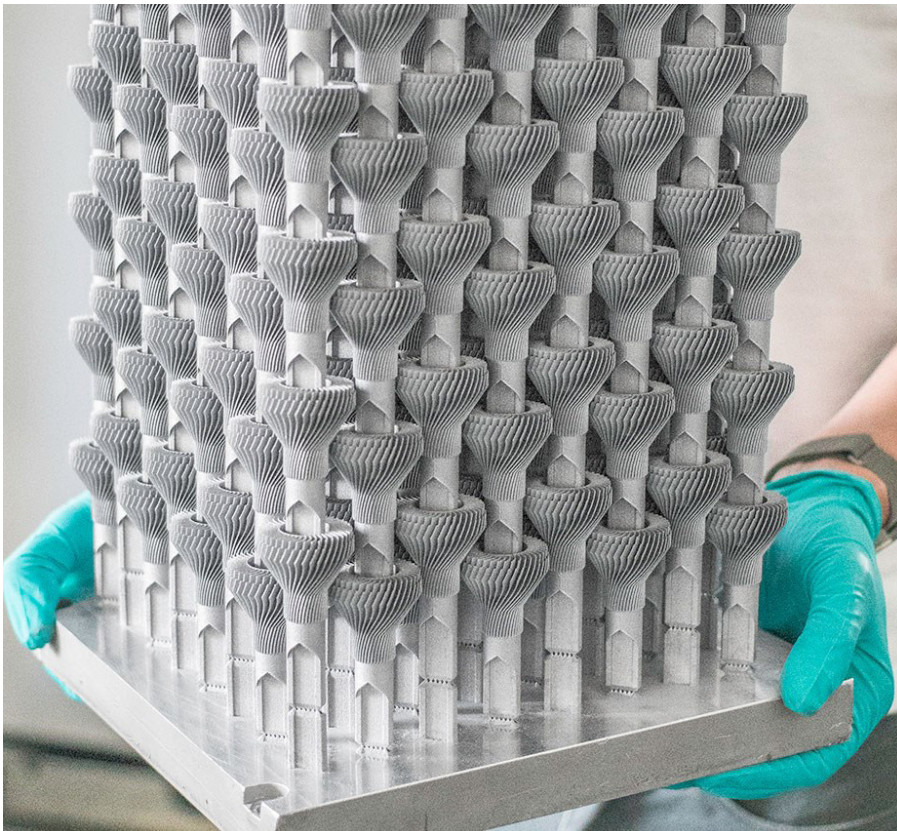
Furthermore, the **relative position of lasers with regard to the gas flow is pivotal**, governed by laser assignment choices made during build preparation. Needless to say that gas flow configurations vary from one machine to another.

“In most cases some sort of attribution of the lasers to the parts has to be done by the operator. This means if you have multiple pieces on the build plate you need to assign which laser should work on which part. Because multi-laser machines are



Dr. Ing. Dominik Schmid, Sr. Engineer, at Kennametal.

more expensive and build times are shorter, the scheduling of builds and planning of shifts becomes even more important to minimize unproductive time and maximize productivity and efficiency.”, **Kennametal’s** representative comments. Speaking of gas flow and thermal stability consideration, he adds: “When using more than one laser simultaneously, the fumes from one process zone should not interfere with the laser beam(s) active in another area. This needs to be resolved by the inert gas flow direction in combination with timing and local attribution of lasers. At the same time multiple lasers bring more energy and thus heat to the building chamber. A part of that heat goes into the gas flow, the other into the machine frame. This has to be taken into account at the machine design. The powder management is virtually independent of the number of lasers sources/optics.”



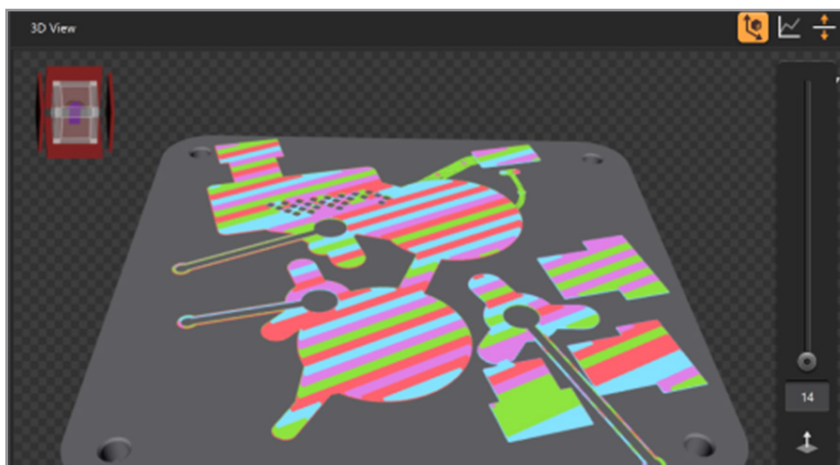
384 heatsinks for LED headlights in one build: Full stacking is often deemed extremely difficult with LPBF due to the thermal stresses involved in the layer process. By intelligently designing the structure to reduce thermal stresses, Betatype successfully made it a viable option with minimal thermal distortion. Credit: Betatype.

So, how do you determine your build strategy?

While manufacturers often use multiple lasers, either to build simultaneously a single component or to build individual parts with each laser, they should assess the turnaround time on the 3D printer, “as the goal remains to maximize laser utilization”, **Rao** highlights.

“What’s the point of having more than four lasers if you only take advantage of one or two? In the end, the more lasers you have, the more expensive the system is. The rise in capex needs to be offset by higher productivity. However, productivity is also influenced significantly by build time and shift patterns [and this depends a lot on the application you want to achieve]”, he continues.

Lastly, one item that is often overlooked in this assessment is software while, as per Rao’s explanations, it plays a big role in optimizing the process and thus achieving quality parts. As a matter of fact, engineers perform and determine all laser operations through software tools. Sometimes, achieving quality parts is often hampered by



Laser task assignment can be quite flexible. | Courtesy of RENISHAW

the lack of the right software tools. Taking the example of Additive Industries, he said their team has been working on developing dedicated software solutions for dynamic laser assignment, qualification and multi-beam tool calibration and they also invested in CFD and real-world analysis solutions.

Conclusion

Surprisingly, lasers hold a major role in a variety of industries such as telecommunications, instrumentation, medicine, computing and entertainment. In conventional manufacturing, one has

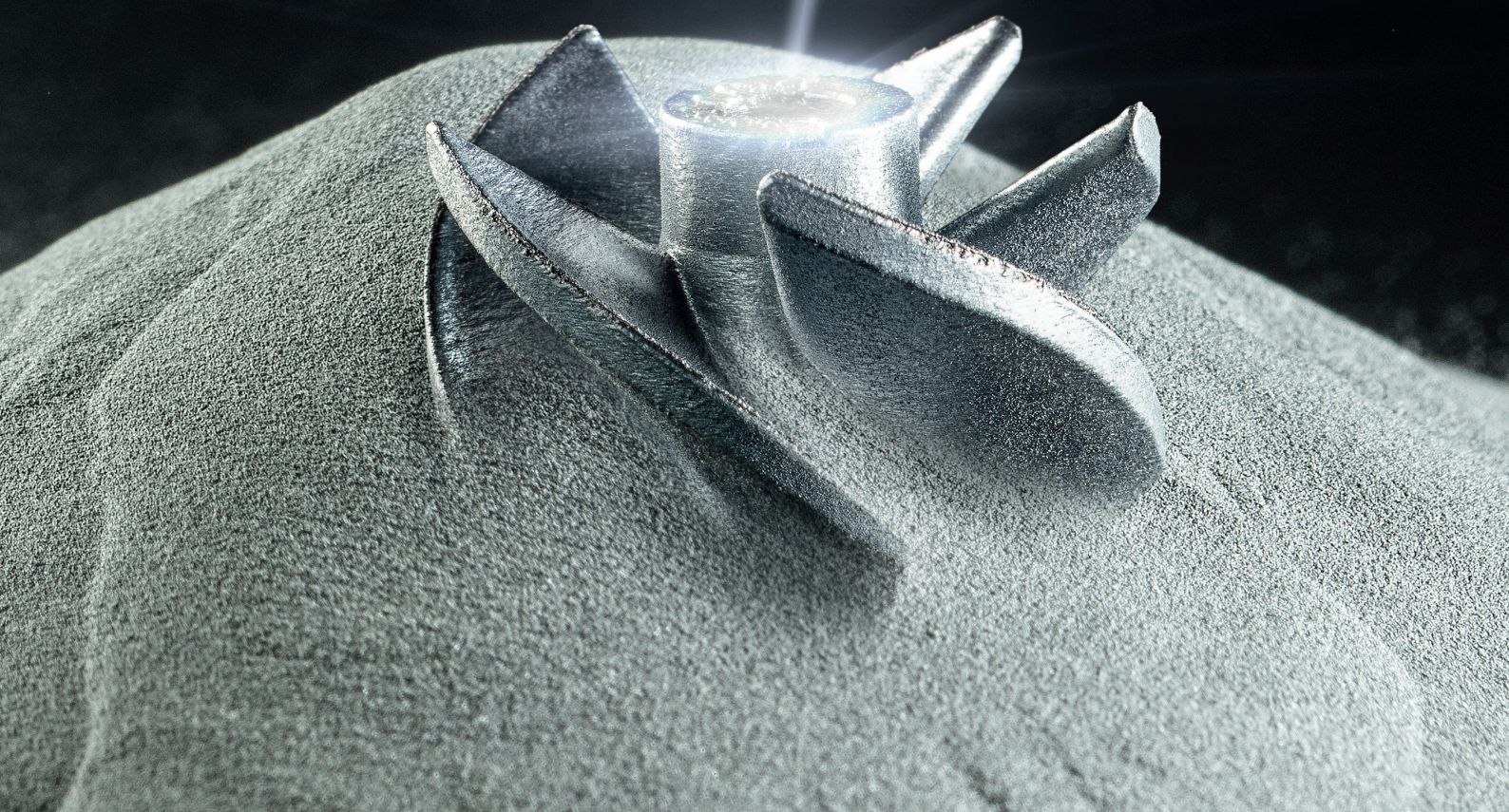
observed their applications in processes such as cutting, drilling, welding, bending, cladding, cleaning, marking and heat-treatment. For such a versatile tool with an outstanding portfolio of applications, its ability to scale up in a technology sector like AM depends on the user ability to better define their requirements. In fine, a thoughtful analysis of the “why” and “how” of multiple laser AM systems, can definitely lead to increased productivity, fabrication of large size parts and reduced cost per part.

A few notes on the contributing companies:

Kennametal works across multiple types of additive technologies to drive improvements in both the solutions they make and how they make them. For example, multi laser powder bed fusion is the right choice for their hot work tool steel products because they achieve the desired material properties in combination with high accuracy and a simple process chain. At the same time, Kennametal applies binder jet printing to produce high quality solid carbide tools and wear components because they can leverage powder and sintering capabilities in conjunction with this additive technology. Every 3D printing technology comes with unique considerations; the challenge is to match the right technology to the right application to unlock the full benefits of AM and drive the biggest benefits for them and their customers.

Additive Industries is a 3D metal printer manufacturer for high-quality metal parts. It offers a system specifically aimed at high-end and demanding industrial markets. With class-leading build volume, robustness as well as productivity, Additive Industries redefines the business case for aerospace, automotive, energy and high-tech equipment. Headquartered in the Netherlands, Additive Industries has demo and service centres in the USA and UK and is a global key player in large volume metal printing systems.

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AMSC 2023

The International Catalogue of AM Solutions

Although additive manufacturing is hundreds of years old, the last five years have been marked by the rise of a number of industrial revolutions and awareness on the technology potential by professionals.

The only thing is that, once you've decided that Additive Manufacturing/3D Printing is right for your project/business, the next step might be quite intimidating. In their quest for the right technology, be it by email or during 3D printing-dedicated events, professionals ask us for advice or technical specifications regarding different types of 3D printing technologies & post-processing solutions that raise their interest. Quite frequently, these technologies are not provided by the same manufacturer.

The International Catalogue of Additive Manufacturing Solutions comes to respond to this specific need: be the portal that will provide them with key insights into valuable AM & post-processing solutions found on the market.

More importantly, an important focus is to enable potential users to leverage the latest developments in Additive Manufacturing. Companies can now feature the strengths of their AM Machine / Material offerings.

Please note that the International Catalogue of AM Solutions is distributed in all industry events where 3D ADEPT is a media partner and to our subscribers at home/in offices

Additive Manufacturing / 3D Printing



AM SYSTEMS



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MATERIALS

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The investment landscape is changing. What should founders consider to grow their AM business ?

“Capital is going to be hard to come by.” These words were uttered twice in the exact same way in two separate interviews with two financiers of the Additive Manufacturing industry. With a tumultuous 2022 marked by one of the highest inflations ever and a tightening of global monetary policy, hearing these words in fine, is not that surprising. Those financiers just expressed out loud what many people were thinking to themselves. So, yes, capital is going to be hard to come by, but what matters here and now, is the founder’s ability to understand this changing investment landscape and how they will adjust to get funded and grow their AM business. Helping executives and founders understand this “new” environment is what we ambition to achieve through this exclusive feature.

A couple of years ago, just before COVID-19, trade press of our industry were full of headlines announcing “Company X” raised money, leading to rapid growth, leading to more money being raised and so on. With those headlines, it was easy to feel we were living in an era of “free money” that fostered a “growth at all costs” mindset among many companies. These headlines had somehow defined “**growth**” as an important factor to get funded, to give credibility to a product that was not always or necessarily viable.

“If I look at investors perspectives – [understand here VC investors, private equity firms or public institutions] – and what they might be looking for at a given time, I would say they are currently being driven by the macro environment. During the last 5 to 10 years, we lived in a world with low to no interest rates, that was flush with liquidity, and that translated into to a very low cost of capital. Often times, high growth investments are in favour in that type of environment, and that had driven investors, especially VC investors, to embrace this “growth-at-all-costs” mentality. The idea is, if you grow and establish something, you don’t have to worry about profitability today as there would always be an abundance low cost capital in the future when it was needed. Profitability and cash



flow generation could follow further on down the road”, **Stephen Butkow**, Managing Director at Stifel Financial Corp explains.

2022 saw a fundamental shift in the macro environment including continued COVID-19 lock downs in China causing both supply and demand issues, soaring energy prices resulting from the Russian invasion of Ukraine, and a rapid rise in interest rates as central banks looked to stem a persistent rise in inflation, all of which made investors more risk adverse.

“The problem is not always the fact that the rates are so high, but the fact that they expanded so fast. This has caused a massive rotation out of high growth sectors, such as Additive Manufacturing, which has made the fund raising environment more challenging for everyone”, **Butkow** continues.

Interestingly, the comment of **Arno Held**, Managing Partner at AM Ventures, completes in a certain way Butkow’s explanation, as he encourages to avoid generalization:

“Not only was this “growth-at-all-costs” mentality mainly observed before the crisis, it was also mostly observed in certain cultures/areas. Across various industries, some VC investors were looking for founders with such type of mentality to fund start-ups. However, today, the paradigm shift in the analysis process of VC firms and other financing companies puts on the forefront that there are more important goals to achieve within a start-up and these goals (sustainability, healthy revenues for instance), are often the ones to make the balance tilt in favour of an investment – thus making the “growth-at-all costs” mentality gradually become a thing of the past”.



Arno Held,
Managing Partner at AM Ventures



Alexander Schmoeckel,
Associate at AM Ventures



Stephen Butkow, Managing
Director at Stifel Financial Corp

“Growth-at-all costs mindset had this assumption that capital will always remain readily available and cheap. An unseen amount of VC money therefore was entering the ecosystem, changing the value-risk appreciation of investors across the VC ecosystem. With the current macro trends, this has changed, leading investors to focus on sustainable growth. However, most importantly, growth and profitability have not to be mutually exclusive.”, **Alexander Schmoeckel**, Associate at AM Ventures adds.

Apart from securing financial rounds, mergers and acquisitions (M&As) remain the most highlighted route through which AM start-ups leverage financial resources. As a reminder, we recorded **over 53 acquisitions** (including SPACs) throughout 2021 – the biggest number ever reported since AM has been recognized as a true industry – **over 21 acquisitions reported in 2022**. The fact is, unlike in 2021 where the need for more financial resources was the main driver of these mergers & acquisitions, acquisitions reported in 2022 raised a number of questions regarding the real strategy of both buyers and sellers.

Is the seller only looking for capital? Was the seller only looking to grow their company until it is ready to

be acquired? Does the buyer have a more thoughtful strategy in mind? Does the buyer just want to buy to kill their competitor’s business? * In the end, for who exactly are M&As a growth strategy, for the buyer or the seller?

For representatives of AM Ventures and Stifel interviewed, these are interesting but very complicated questions that absolutely require to look at both sides of the story: the **acquirer** and the **seller**.

“If done well, this can be a growth story for everyone”, **Held** points out. “Acquisition in itself is a capital investment. Now, the reasons of the acquirer always vary from one company to another. The acquisition can serve a very specific growth strategy in mind: [**product development** – new products in existing markets–, **market penetration** –existing products in existing markets–, **market development** –existing products in new markets– and **diversification**]. It’s a very rational decision that involves a thorough analysis that goes beyond financial resources to encompass the timing and go-to-market capabilities”, he states.

Butkow on his side lays emphasis on the seller side of the equation and his analysis pinpoints 4 items that in my opinion, should always be analyzed together: **management strength** (business acumen vs technology acumen), **ability to scale, cost to access target market, definition of success or accomplishment** – i.e. how far they want to scale the business. He explains:

“We surround ourselves with a lot of brilliant people who are typically mechanical engineers, computer science engineers or a mix of all of them, who have developed and turned great products into commercial business. And it’s very rare for a person to be an expert in one niche be an expert in everything. So, just being a fantastic engineer does not necessarily mean you’re a fantastic business person. The fact is, it takes a village to be successful, and grow a business. In this vein, it’s almost always

accurate that a founder that takes a business from 0 to 10 million euros in revenue, is not the person that takes the same business from 10 million euros to 100 million euros, and so on. It requires a different skill set for every single milestone. That's why there is very often a change in leadership every time a company achieves a milestone. Management quality is therefore as equally important as technology. It cannot just be overlooked.

On another note, our industry has failed many times because founders have been able to develop a viable technology but they don't have a sound business model. Therefore, they found themselves in a position where they either have to constantly raise capital to scale or sell their technology to another company that already has all the infrastructures in place to implement a go-to-market strategy. At that particular moment, the founder is certain their technology is going to survive; it won't survive in the exact form they initially planned, but at least it won't die because of a lack of capital. It comes back to what was said earlier: the founder was the right person to move the business from 0 to 10 but is often times not the right person to move it from 10 to 100."

Butkow's explanation somehow opens up a more personal question every founder should ask themselves: what would make my business successful? Or how do I measure success? I know a couple of founders who take pride in building their company from scratch, every step of the way. I also know a couple of founders who are proud to have developed a technology, and scale it with the support of a parent company.

As Schmoeckel notes, "an entrepreneur might define [success] according to whether the new venture achieves personal fulfilment, an investor considers success



more from a financial perspective, for example, whether the portfolio firm generates the desired rate of return. The most appealing approach to measuring success is by profitability. However, such data is largely unavailable to privately held companies. Differences between various investments in product and market developments enormously affect reported profitability. In addition, performance measures such as return on sales or net profit are more relevant for companies in their later stage. Early-stage startups are different, as they may initially have little or no revenue to report, and growth rates do not fully represent the real value of an early-stage firm".

That being said, it should

be noted that for VC firms – just one way AM Ventures considers success –, a successful startup is one that has secured at least a Series A VC funding round or has even managed to go public or be acquired by another company. A growing number of employees is also a direct indicator of growth for VC firms, as it serves as a proxy for the growing managerial complexity.

For that to happen, founders or executives should be able to raise capital every "18 and 24 months. This timeframe should be the ideal way to go. This means that founders should establish business plans that last about 24 months – knowing that money always goes faster than expected", Held outlines.

What should founders be considering to grow their AM business?

So, yes, with the macroeconomic projections, there are potentially some very challenging times ahead. Some companies will struggle to raise further capital but this does not mean it will be impossible. As **Held** says, “we should be careful not to fall into a big “panic” move”. No matter what the projections say, “at the end of the day, investors are buying risks. The most-risky investment in the world is a start-up. [However,] investors need to understand why the solution they invest in, needs to exist. [There must be a compelling customer value proposition]”, **Butkow** states.

I think, we can all agree that growth for growth's sake without a sanity check on efficiency, sustainability, or profitability will bring you nowhere. Based on our conversation with these three experts, we can summarize some of the crucial points that may require specific attention as follows:

- Investment in the private AM market is being explored and that there are still opportunities despite the changing investment landscape
- Funding will likely be more applications vs technology based.
- Customer adoption should be a key area of focus.
- VC firms like AM Ventures will be looking at companies that achieve profitability right from the start. Not achieving profitability within a year or two will not be a deal breaker but do not make ridiculous assumptions on your profitability.
- Investors will be looking at start-ups that have a great management team. As capital becomes more uniform, the quality level is usually on the management side, so they will be looking at the team who will be able to bring the company to the next phase. Management teams who will be a bit honest



on their story and where they will go, will attract more capital.

- A working business model and a strong leadership should not come at the expense of value or the team behind it.

- Big companies that went public and made a lot of promises on growth will be evaluated both on growth and profitability.

- Investors almost always go back to the basics. That's a world where cash is expensive, people have to be disciplined with their cash.

- Investments are principally made with an expectation of a rate of return based on a future value discounted back to today - will it be worth more than it is today in some defined time period?

- Consolidation will happen for a multitude of reasons

- Reasonable Valuation vs 2020/2021

- Need for / Ability to attract capital

- Need for scale to achieve profitability - lack of operating leverage

A few words on AM Ventures and Stifel

If you're a regular reader of 3D

ADEPT Media, you probably already know **AM Ventures**, this VC firm that decided to grow the entire industry by investing in forward-thinking AM companies across the materials, software, hardware and applications fields. With 17 portfolio companies across the world, AM Ventures emphasizes the need for companies seeking [funds to choose the “right investor” and “to prioritise collaborations over acquisitions”](#).

Stifel is a diversified global wealth management and investment banking company with a focus on serving small and mid-cap companies. Their investment banking division provides M&A advisory, capital raising and equity research. They are one of the most active investment banks in the AM sector being involved in over 20 transactions, over the last two years, including the likes of advising ExOne on their sale to Desktop Metal and 3D Hubs on their sale to Protolabs.



Bootstrapping vs Fundraising: How Makelab successfully navigates a labyrinth of uncertainties.

This article is the second part of a series dedicated to the changing investment landscape in the AM industry. The first part, featured on page 13 of this magazine, discussed what founders – who will be looking for funding this year – should consider to grow their AM business.

Many of you probably know **Christina Perla**, as the founder and CEO of Brooklyn-based 3D printing service bureau **Makelab** or through her work with **Women In 3D Printing**. I have been lucky enough to discover her bravery in running an Additive Manufacturing business while navigating a labyrinth of uncertainties and this is one of those genuine experiences that mark the life of every editor.

If you're a founder or executive running a business, you probably already know that "capital is going to be hard to come by." Investors and financiers have said it repeatedly, even in this edition of 3D ADEPT Mag. While the trade press has contributed to putting on a pedestal companies that continuously secure funding rounds from investors and other financial firms, the majority of entrepreneurs (75% to 85%) are bootstrapping their companies – which can be hard to believe because no exact figures have yet to be shared in our industry. However, it turns out that, I know a couple of AM companies that rely on their resources to grow their business and Makelab is one of them.

The truth is, in my modest experience of engaging with start-up founders, I have developed some sort of awe for them – for those who struggle and for those who thrive – because in the end,

it takes a lot of courage to pursue this road.

With the changing investment landscape, I believe this conversation is more important than ever, as it strikes a balance between the two parties – those who are bootstrapping their business and those who go the VC route. Interestingly, it aims to give those of the former group a couple of options they should continue exploring in their journey.

Perla on the “growth at all costs” mentality

For the record, Makelab emerged in 2017 and since then, continuously invests extra miles to support businesses alike across vertical industries that may benefit from AM. According to Perla, the company was born by accident by two industrial designers who thought they were going to build a design firm. The intent with Makelab was that it was a cash-rich business that could fund the growth of the design firm.

“2-3 years in, Makelab tripled, we found a real problem that existed in the market that no one seemed to be really hitting the mark on, and my cofounder & I truly enjoyed building a business and the process of simplifying a complex operation. What we saw was that most of the industry was truly focused on advancing AM, focusing on metals and new use cases. Manny and I love that, we support it. But as industrial designers ourselves, it seemed that no one was really building a solution for designers like us, for those in the consumer products space. Whatever was out there, seemed to be just missing



Christina Perla, founder and CEO of Makelab

the mark, according to our customers”, she states from the outset.

The reality is, the company has been evolving in an industry where newspaper headlines had somehow defined “growth” as an important factor to get funded, to give credibility to a product that was not always or necessarily viable. While she believes that, to never lose sight of the real business, one should remain customer-centric, Perla recognizes there are many startups/companies out there with a “growth-at-all-costs” mindset that still haven’t hit product-market fit:

“They target everyone, and in doing so, they target no one. I believe that the pressure of that mindset can be detrimental if it’s brought on too early. When building a solution to a problem, you must first find it. Sometimes, that takes more time than the timeline that VCs

and other founders give. But if you want to build a solution/product that lasts, it’s good to sit with it for a while.”

By focusing on your real targets, the latter will give you validation of your products as you grow, and VC money will only be “a tool to help you get to where you’re going faster. It’s not the end goal, and if it is then I would question the founder + the business”, she adds.

So, how does one manage to grow on their own?

Whether their company is successful or not, the founder will always need to pay bills, ensure healthy future cash flows, and as alarming as it sounds, capital sources can dry up overnight with no warning. Bootstrapping appears then as a double-edged sword: on the one hand, you have no dependence on investors and a lot of time to strengthen the foundations of your business, on the other hand, addressing

the challenges and impromptu situations that may require (a lot of) cash flow, can be frustrating, time-consuming and slow down the process of building the road to success.

I was curious to know how Makelab managed to grow without raising money. Did they decide not to raise money or were they not given that opportunity? Most importantly, how did they overcome the toughest periods of the financial crisis? The honesty in her responses comes with a couple of lessons she learned from this period:

“It wasn’t even on our radar until 2020. It wasn’t until we tripled the business that we considered it. Growing is tough when bootstrapped. It’s a cash flow management + timing game.

In Q3 of 2020, we went out and tried to raise. We failed the first time. We went out again in Q3 2021 and succeeded. But it turns out the fund didn’t have any capital



to deploy. In 2022, we decided to minimize our efforts (while keeping the door cracked with warmed relationships) and focus on growing our revenue and customers.

In a way, we weren't even given the opportunity. Our business is tough, when you compare us to software SaaS models, the competition is stiff. SaaS wins. At the end of the day, dedicating 8+ hours a day to fundraising when we had little success, didn't feel like the right move for us at this time.

Bootstrapping isn't for the faint of heart. It's tough, very tough. Many funded founders talk about runway and the cash in the bank dwindling. Well, in bootstrapping, you'll experience many of those on a smaller scale. The good thing is- if you're winning with your customers, you have revenue. If you have revenue coming in, it's easier to weather those cash flow storms.

Many of the principles and tactics for cash management I did while bootstrapping should really be applied across the board. But the stakes are different. With bootstrapping, there is no boat coming to save you. No chance of a boat. It's just you. The more predictive you can become with the cash that enters and leaves your bank account, the easier it will be. You should know everything down to dates & amounts. How much do you predict your bank account will be

in 2 days, 4 days, 4 weeks, 4 months."

What tips founders who are bootstrapping should keep in mind then?

Let's make it clear: if you have no means to finance even a small and steady version of your business/project, then this article is not for you. You may want to explore other financial alternatives. However, if you decide bootstrapping is the best choice for your situation, a couple of strategies may get you on the process of building the road towards success:

- Select your team members wisely. "No company, small or large, can win over the long run without energized employees who believe in the mission and understand how to achieve it."

- Be prepared to take on many roles, including those you feel are subservient.

- Make sure you outsource what's essential (e.g: legal and accounting).

To these tips, Perla adds:

- "Prioritization is key. You can't dwell on something that 1) hasn't happened yet, 2) is out of your control. That will only blind you from seeing potential solutions.

- Get creative. This is where being a New Yorker really comes in handy. Get creative and think outside the box. If there are any non-dilutive capital opportunities- grants, micro-loans, etc. - take

them. Apply for them, and learn how to seek them out.

- Don't get comfortable with loose expenses. Know where your money is going. Guard it with your life. Be smart about how you spend, you don't have the same luxury as your funded friends. Find credits, find deals, and find ways to get free months on software products. All of those things add up and can help a lot."

Just like each AM application is one of its kind, keep in mind that there is no "one size fits all" funding formula for start-ups. Moving forward, and speaking of Makelab, Perla's statements here do not mean that VC or other investment instruments are out of the question completely. "But at this moment, we're choosing to focus on our customers and our business", she concludes.

Last but not least, no matter how complex the journey is, I believe defining your measure of success will help you appreciate each stage of the journey at its true value.

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Just under 40,000 bus spare parts are already 3D printable today. Some of these are already available only as 3D printed spare parts after having undergone the relevant digitization steps, approval processes and numerous product tests. Image via Daimler Buses.

(Critical) Challenges raised and solved by high-performance polymers for AM – Key examples in the automotive industry.

In an industry where the growth of AM is often highlighted through a strong focus on metals, it should be noted that polymers remain the widely used material group, all applications combined. Industries such as aerospace, automotive, and biomedical are exploring applications of high-temperature polymer parts with AM, but a gap still has to be filled for them to achieve series production.

Let's be clear: plenty of examples have already demonstrated that high-performance polymers processed via AM, have enabled the fabrication of tooling or end-use applications. The fact is, for those materials to be considered as a replacement of metals, for them to deliver high-value parts in low-quantity production runs, there are a number of requirements they should meet.

This article ambitions to outline the challenges manufacturers still have to address when adopting high-performance polymers in series production, and the ones these materials can already solve at the manufacturing level.

While various contributions have been considered, **Sylvia Monsheimer**, Head of Industrial 3D Printing & New 3D Technologies at Evonik, has been invited to share key insights alongside **Ralf Anderhofstadt**, Head of Center of Competence Additive Manufacturing, Printing Shop & Media at **Daimler Trucks & Buses**.

Evonik Industries AG is a stock-listed German

specialty chemicals company, that develops and commercializes one of the most comprehensive portfolios of material solutions in the AM industry under the brand **INFINAM®**. As far as materials are concerned, the company's high-quality polyamide 12 powders are acknowledged for their multi-purpose applications in the AM industry. The company's experience in developing polymer-based 3D printing materials will enable us to put ourselves in the shoes of a material producer and to understand the complexity of high-performance polymers.

[Daimler Trucks & Buses](#), on the other hand, will bring their expertise as an AM user. For many people, this company is just the largest commercial vehicle manufacturer, with over 40 production sites around the globe and more than 100,000 people at more than 40 locations across the world. In the 3D printing field, the automotive maker benefits from over 25 years of experience in 3D printing prototype construction. With 50,000 3D printable bus spare parts available today, the company mostly used AM in the after-sales division, to react fast and flexibly

to urgent customer requirements, for example when customers order rarely required parts or have special requests.

Anderhofstadt told us they currently work with numerous partners and service providers, which is why they test all known production processes in AM and test them for series suitability. At the moment, their focus is on SLS, MJF and, of course, FDM, depending on the application.

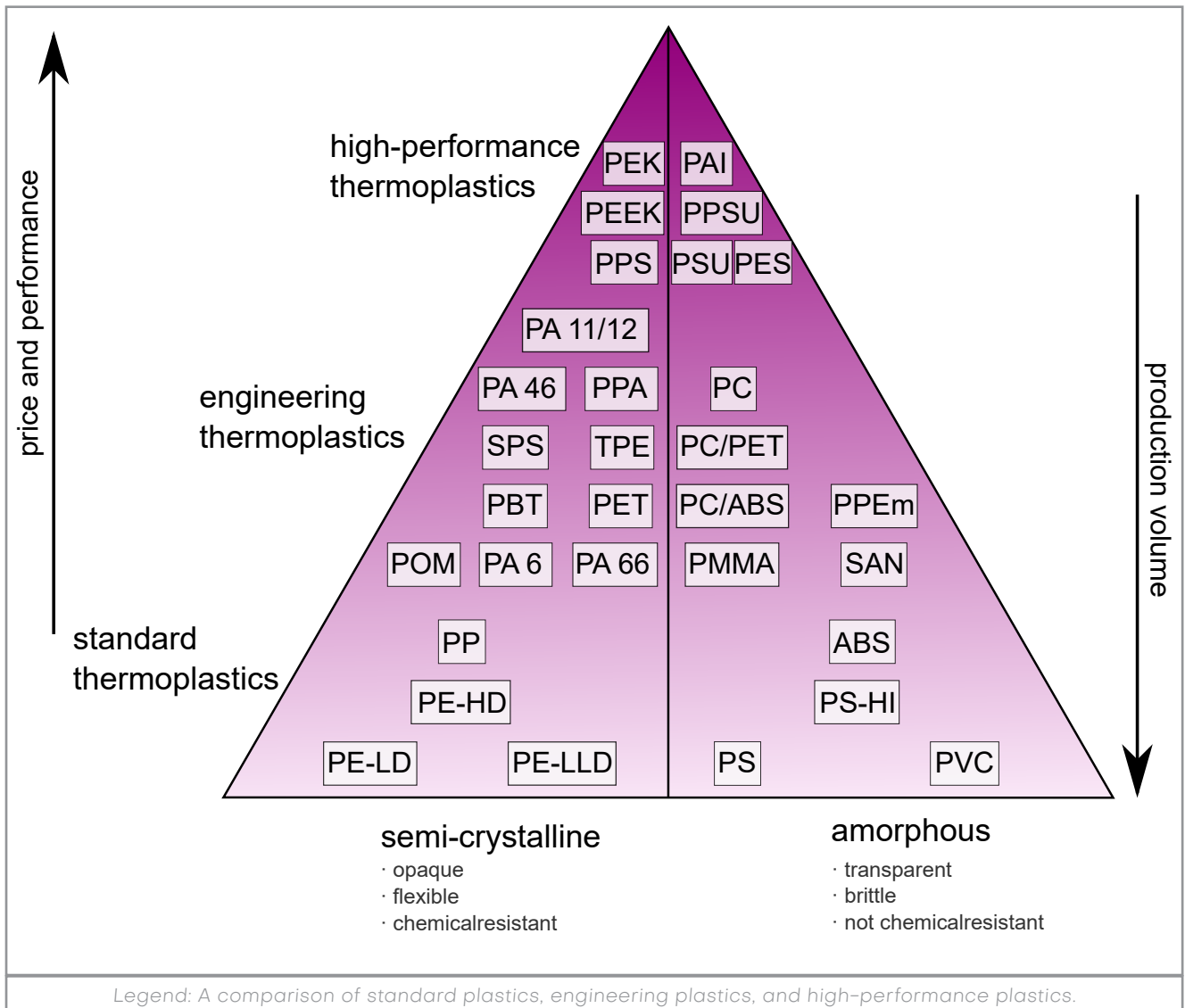
Understanding the concept of “high-performance” polymers

If you’re new to this world, please note that the term “polymers” is often used interchangeably with “plastics”. However, we will mainly use the word

“polymers” in this article.

Technically speaking, [high-performance polymers](#) (HPPs) are a group of materials that can retain their desirable mechanical, thermal, and chemical properties when subjected to harsh environments such as high temperature, high pressure, and corrosive chemicals.

While the term “high-performance” is now naturally used in the scientific and industry jargon, the truth is, it is not a scientific term per se. Nevertheless, it helps define a specific category that is at the head of a pyramid highlighting polymers’ performance. High-performance polymers are located at the top of the polymer pyramid and are directly followed by engineering polymers and commodity/standard polymers.



The last time we checked, **high-performance polymers constituted about 700,000 tonnes or only 0.2% of all man-made polymers.** They are typically much more difficult to manufacture. Since they are based on more complex monomers, they turn out to be

quite expensive. That being said, the more complex or difficult the polymer material is to produce, the more performant the resultant polymer is.

Generally speaking, polymers provide a lot more of advantages than metals: they are more resistant to chemicals, they do not

require (a lot of) post-treatment finishing efforts, they are lighter than typical metals, or they are naturally radar absorbent as well as thermally and electrically insulating. It’s fascinating how some of these properties are also sought out in HPPs developed for AM.

“A significant advantage lies in the high-temperature resistance, which is why this is also very interesting for the automotive sector. This is of course underlined by the properties such as high tensile strength and high chemical resistance. As a result, high-performance polymers are increasingly becoming an interesting alternative to metals, **Daimler’s** expert points out.

Surprisingly, the properties that make high-performance polymers helpful are often the ones that make them difficult or impossible to produce using common AM machines without high heat processes.

“If we’re talking about series production – parts that are produced for an end-use application – we will meet the following challenges then: We do not only have to replace the step of building a part but also adjustments of production process steps before and after building a part have to be considered and proven. In other words, we have to work on the integration into process

chain which mainly is application driven. And turnkey solutions as a whole are not available. However, this point always is underestimated”, **Monsheimer** states from the outset.

Anderhofstadt agrees with her as he emphasizes the **need for technical and qualitative release processes**: “for series parts, it is of course essential to achieve 100% of the properties of the part in the overall context in order to achieve the quality standards. This is also the basis for reproducibility, which is absolutely necessary for series production.”

Added to that the “costs consideration”, and you make the conversation encompass the entire manufacturing chain:

“Another challenge for sure are costs of the overall 3D printing solution. The competition with injection molding is unbeatable for a large number of simple parts. Additive Manufacturing technologies in general offer advantages if freedom of design can be used or



Ralf Anderhofstadt
Head of Center of Competence
Additive Manufacturing

assemblies made in one part can be done. In doing so, [it is necessary to redesign the part(s) with AM in mind]. Eventually, special materials for special applications are still missing. Here we step in by continuously extending our product portfolio of application-driven 3D printing materials”, **Evonik’s** representative adds.



Images via Daimler Buses

So, what challenges are we talking about?

“Challenges” is a big word that is regularly used in every topic related to AM. In this specific case, I would like to think of them as limitations that lead to new opportunities for AM users.

The first thing we will keep from Monsheimer’s latest comment is **the limited number of high-performance polymers**. Interestingly, the process is not as simple as creating forms of

traditional polymers used in injection molding for AM.

The problem of **“delamination”** at the manufacturing level. According to machine manufacturer **Orion**, parts that are specifically made from PEEK, often suffer from this issue. This means that the fused layers that build the final shape are not properly welded together. These faulty PEEK parts behave more like a stack of

loosely connected slices than as a continuous whole. These uneven mechanical properties are referred to as “anisotropic properties” and are a common problem in printed parts from many manufacturers. They have been able to explore a new solution to this problem when they were working on the AM of CubeSats, those miniature, lightweight satellites used for space research, earth observation, or telecommunications. The team used their **Thermal Radiation Heating system**. Developed in-house at Orion, it fuses the layers together while heating the entire object and directing thermal radiation to the previous layer before new material is deposited. Every layer of the printed material is molded to the previous one with selective heating up to 300 °C. This ensures that the layers form one strong and continuous part. It produces stronger, more isotropic 3D printed components that are ready for immediate use, Orion explains.

As you may guess, if not addressed, this problem often leads to limitations associated with large thermal gradients, residual stress build-up, and interlayer adhesion as well as the inability of the 3D printers to consistently maintain required high processing temperatures. That’s the reason why we will never stress enough the need for collaborations between material manufacturers and technology providers, as **Monsheimer** recalls before adding:

“A good material is the key! This means, having a safely processable material fulfilling all needs 3D printing processes or the respective application require - at the best price. If this setup of material properties vs. costs ratio is given, we can start working on other challenges.”

Another limitation can be seen in the type of applications achieved with these materials. For instance, due to their low structural rigidity, heavy structures are difficult or rarely

achieved with polymers. That’s the reason why most applications are portrayed in the healthcare industry, in the jewelry industry ([Boltenstern](#) for instance, offers mass-customized earrings or bracelets in various colors made from Evonik’s PA12) or for customization purposes in other industries. In the automotive industry though, there is high hope to witness a couple of new applications soon:

“We are currently in some final testing of high-performance polymers for series applications. The first information on this will also be officially announced soon, as this range is also very interesting for us in the truck and bus sector.

*We have already installed more than 50,000 3D-printed series parts in our vehicles. The focus is currently still on the polymer sector, but we have already implemented several series applications made of various metals. In addition to brackets, various covers and handle inserts in the metal area, typical parts are also carriers or various components on the exhaust system”, **Anderhofstadt** enthuses.*

Moving forward, and with regard to the automotive industry, Anderhofstadt points out the need for high-performance polymers to meet other requirements:

“I am thinking strongly about properties such as fire protection and thus the flame retardancy of the materials. And of course, this must also be in line with the sustainability goals. And to supplement this even further: for series production, it is essential that these materials can be used



Sylvia Monsheimer, Head of Industrial 3D Printing & New 3D Technologies at Evonik

for economical production”, he completes.

Monsheimer cannot disagree with him on the sustainability point – as she also points out this concern. As a matter of fact, the carbon footprint and/or disposal can be critical issues as some polymers cannot be recycled while all metals can. However, some material producers have started taking action to address this issue – and Evonik is part of them as you may have read in this issue of 3D Adept Mag (page 25).

“After prototyping, applications are the next challenge for materials because now materials have to be optimized for particular applications”, **Monsheimer** concludes.

UNBOUNDING 3D PRINTING AT SCALE WITH NEW SUSTAINABLE MATERIALS

By its very nature, Additive Manufacturing is considered a sustainable technology. The sustainable advantages of 3D printing could play an important, even decisive role for producers and manufacturers towards series applications. For material manufacturers like Evonik, living sustainability might not be so self-evident for everyone. But the more aware and transparent the sustainable journey becomes at the beginning of the additive value chain, the more impact these effects will have in the final application.

With a growing emphasis on environmentally friendly manufacturing, the evaluation of the environmental performance of additive manufacturing processes has gained attention. Additive manufacturing offers several sustainable advantages over other processing technologies: The design freedom of 3D components offers enormous potential for novel product developments and improvements in component efficiency and performance. New bionic lightweight structures enable the best possible design of functional elements, which are primarily used as lightweight components in the aerospace and automotive industries. Due to the general principle of all additive technologies of depositing material in a structured way instead of removing it, as in some other processes such as machining, 3D printing materials are used very efficiently. In the recent past, which unfortunately has been characterized by collapsed global supply chains for several reasons, additive manufacturing has been particularly effective: on-demand production of parts organized in a decentralized manner, is now a reality. That's why 3D printing is often regarded as a sustainable processing technology.

"In our specialty chemicals business with high-performance materials, we don't see the various processing technologies in any sustainability competition," explains **Sylvia Monsheimer**, who heads Evonik's Industrial 3D Printing market segment. *"People often tend to compare injection molding and 3D printing. But there is room for both on the market, and there are good reasons to rely on one or the other technology depending on the application, such as 3D printing for shorter product life cycles or injection molding for high-volume specialty parts."* In addition to the economic arguments, it is impossible to imagine parts production today without ecological aspects. When deciding for or against a processing technology, ecological influences such as sustainability in its many aspects or the various options for recyclability are considered in addition to cost per part.





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For many market players like material manufacturers or technology providers, living sustainably might not be so self-evident for everyone. But the more aware and transparent the sustainable journey becomes at the beginning of the additive value chain, the more impact these effects will have in the final application.

As a specialty chemicals company with a presence throughout the world, Evonik, sees sustainability and long-term business success as two sides of the same coin. That is reflected in the rising demand from customers for products and services that demonstrate a good balance of economic, ecological and social factors. Sustainability has long since developed into a growth driver for Evonik.

Sustainable 3D printing starts with the right material

Yet material manufacturers bear a great responsibility here because the sustainable result of an application stands or falls with the sustainable performance of the materials used. “Sustainability is the core element for being successful in the future. We understand sustainability as a key growth driver and the cornerstone of our product portfolio, investments and innovation management. Sustainability is, therefore, an integral part of Evonik’s strategy”, says **Dr. Dominic Störkle**, Head of the Additive Manufacturing Innovation Growth Field at Evonik.



Dr. Dominic Störkle, Head of the Additive Manufacturing Innovation Growth Field at Evonik.



At Evonik, the polymer experts take a holistic view on sustainability based on four main cornerstones:

- Improving reusability rates
- Reducing carbon footprint
- Saving fossil resources
- Recycling

Alongside factors such as **production efficiency** or the **reusability of materials**, their sustainability approach includes the total **life cycle assessments of materials** and their **consistent improvement**. The specialty chemicals company looks not only at carbon footprint, but also at other important factors such as **water consumption** and **land use**. Using green energy and renewable or recycled feedstocks

for production, Evonik significantly improves their materials' overall eco-balance and works on end-of-life opportunities for the group's polymers.

Improving reusability rates

Evonik already offers its first new PA12 grades which can be reused by only replacing the powder needed for the parts of the previous job, which avoids material waste in production according to the group's ZERO WASTE approach. Furthermore, new powder materials are being developed to increase their reusability rate during a 3D printing process.

Reducing carbon footprint

In October, last year, Evonik

introduced a new grade of PA12 powders with significantly reduced CO2 emissions. The new PA12 powders will replace the previous INFINAM® polyamide 12 materials for all common powder-based 3D technologies such as SLS, HSS or MJF. The new sustainable INFINAM® PA12 powders are produced using renewable energies at the Marl Chemical Park in Germany. TÜV Rheinland has certified the associated life cycle assessments, confirming an improvement in the company's own carbon footprint of almost 50 percent. In the overall life cycle assessment, the comparison of the new sustainable material grade is positive even compared with the castor oil-based polyamides of Evonik's own Terra range.

Reducing carbon footprint



Castor oil-based PA (INFINAM® Terra)

Renewable energy-based PA 12 (INFINAM® PA)

Saving fossil resources

Evonik is also working to expand its range of sustainable PA12 powders to include the INFINAM® eCO product line. «eCO» stands for the company's goal of avoiding the greenhouse gas carbon dioxide by using renewable or circular raw materials via the mass balance approach. Mass balance involves mixing virgin fossil and renewable or circular raw materials into existing systems and production processes. The renewable amount is then allocated mathematically to specific products and is certified by a neutral third party to verify the use of renewable or circular resources across all stages of production. Mass balance is a way to keep track of the renewable or circular quantities throughout the process and allocate them to specific products. It allows for large-scale production and enables cost-effective solutions that meet more stringent environmental and sustainability

targets. The market launch of **INFINAM® eCO** is planned for this year.

Recycling

Finally, Evonik also works on end-of-life opportunities for polymer-based 3D applications.

With a growing emphasis on environmentally friendly manufacturing, the evaluation of the environmental impact of additive manufacturing processes is crucial for choosing case by case the most efficient and sustainable technology for parts production. Life cycle assessment is an important tool to compute the environmental impacts of 3D printing processes. By developing new sustainable high-performance materials, Evonik wants to drive 3D printing as another important manufacturing technology for series production to coexist with injection molding, extrusion and machining in the future. For this, the right materials must be used from the start.

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Evonik is introducing new 3D printing grade of its INFINAM® PA12 powders with significantly reduced CO₂ emissions. The new sustainable materials are produced using renewable energy—based on biomethane—and certified by TÜV Rheinland attesting an improvement in the company's own carbon footprint of almost 50 percent.

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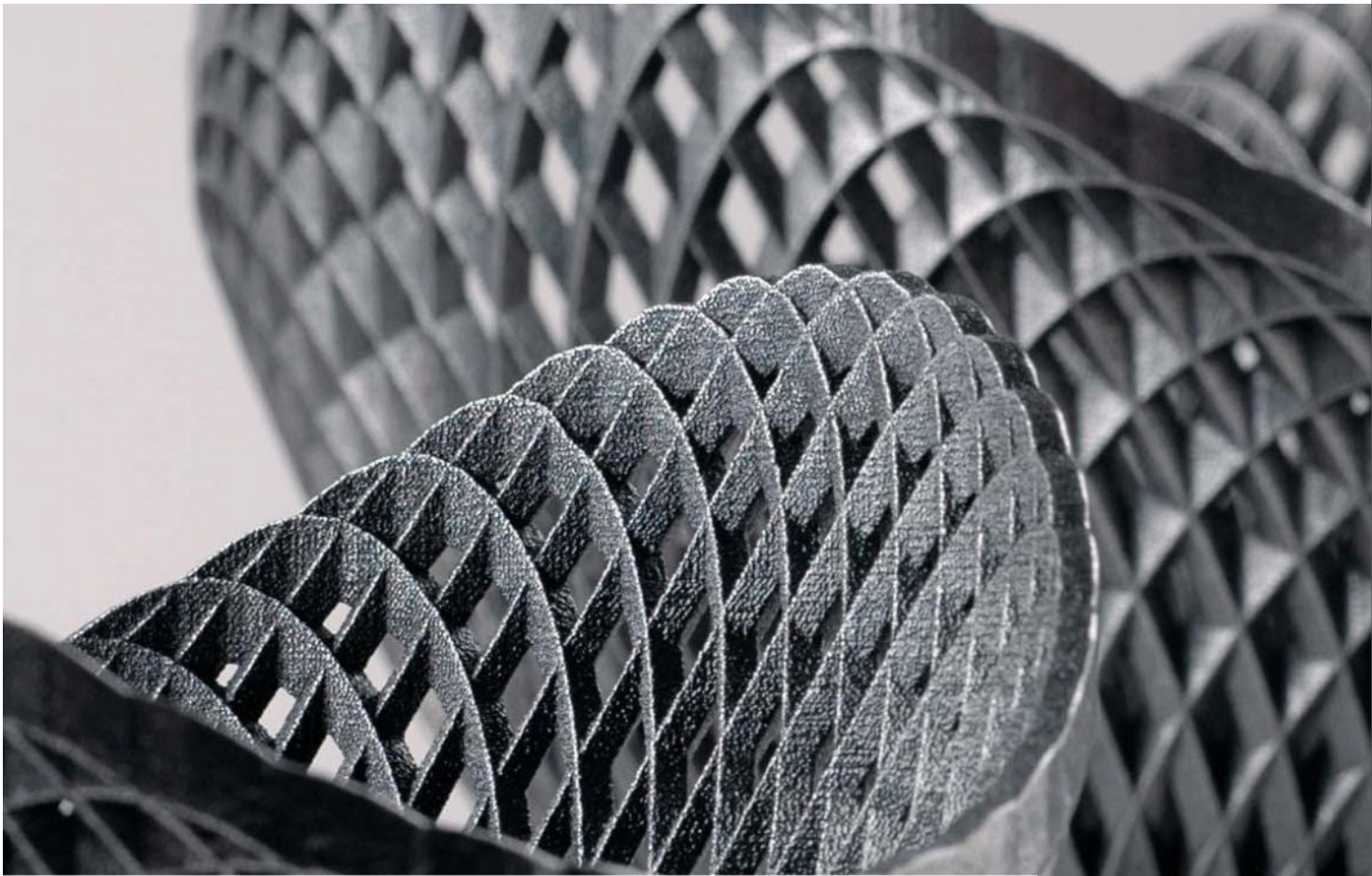
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UNDERSTANDING THE INFILTRATION AND COATING PROCESSES FOR ADDITIVE MANUFACTURED PARTS

Whether it is light or cheap, a 3D printed part delivers value when it performs well. The thing is, achieving that performance often begins and ends at the surface. Ensuring the right surface of the 3D printed part often comes down to the right post-processing task. In our efforts to demystify every post-processing task that can be used at the end of the additive production, we'll focus on infiltration and coating processes in this article.

Remember that **post-processing** is an umbrella term that covers a variety of stages that 3D printed parts have to undergo before being used for their final purpose. No matter what post-processing stage the AM part needs to go through, the goal remains the same: removing the undesired properties that have been built in the final product during the additive manufacturing process.

Among the various

post-processing tasks that can be performed on 3D printed parts, we already studied the [use of furnaces](#), [heat treatment](#), and [metal powder removal](#) in previous editions of 3D ADEPT Mag.

Interestingly or frustratingly, when it comes to infiltration and/or coating, what seems simple is yet indescribably complex. Infiltration and coating are often used interchangeably to signify the same process. Therefore, if you ask 5 experts to

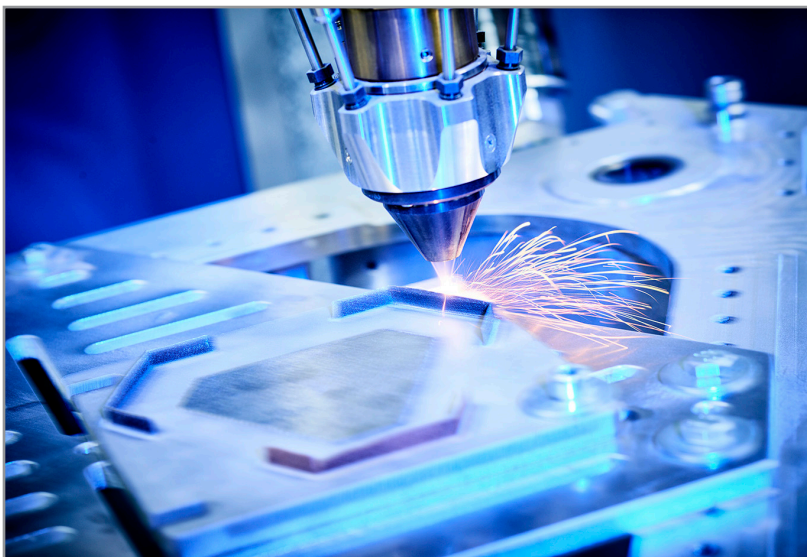
define or explain what they understand by infiltration or coating, there is a great chance you come up with five different meanings.

We did our homework, we talked to industry experts and conducted some research to clarify each of those terms and the way they should be utilized in an additive manufacturing production.

Coating

Coating is a word that is widely used in AM: Surface coatings, Additive Manufacturing Coatings, Coating for AM parts, Dry powder coating, Cold spray coating etc. Simply put, a coating is a layer of a substance added to a surface to provide protection and to enhance the appearance of the surface.

“According to our understanding, [it] is a manufacturing process to refine both conventionally and additively manufactured metal parts. The purpose of a coating is to protect a part from harms caused by the characteristics of its operating environment (e.g. high temperature, high humidity, presence of chemicals, mechanical stresses etc.)”, **Dr. Ing. Tobias Stittgen**, Managing Director at [ponticon](#) states. The machine manufacturer develops a technology that enables objects to be coated and printed at a fast pace. The company’s high-speed DED technology can be applied to coat any 3D printed metal component. Highest material flexibility is achieved by feeding the coating material through a nozzle, enabling application-tailored properties at



a part being 3D printed and coated on Ponticon's high-speed DED system.

unprecedented productivity. In general, to refine metal parts, operators often apply a layer of material onto the substrate to enhance the parts’ surface properties. As Stittgen implies, choosing a coating often depends on what is affected in the operating environment. It also depends on life expectancy, substrate material compatibility, component shape and size, and obviously price.

Furthermore, while coating can be utilized with all metal-based AM processes, it should be noted that “*protective properties are better achieved with materials that differ from*

the actual part’s material. As the coating materials are often high-value, manufacturing the entire part is economically unviable”, Stittgen notes.

In this vein, to help categorize the different types of coatings, operators often look at the way the coating material is deposited onto the substrate surface. Four methods of depositing the coating material have been identified: **atomic deposition, particulate deposition and bulk coating or cladding**. Each of these methods includes a wide range of sub-processes and are compatible with specific operations:

Atomic deposition	Electrolytic deposition	Physical vapour deposition (PVD)	Plasma deposition	Chemical vapour deposition (CVD)
Particulate deposition	Thermal spraying	Impact plating	Enamelling	Electrophoresis
Bulk coating or cladding	Painting and dipping	Laser cladding	Weld overlays	Roll bonding
Surface modification	Anodising	Electrolytic conversion		

Table created by [TWI Global](#).

On another note, surface modification methods used for metal AM include a lot more processes: shot peening, rolling sand blasting, laser surface treatment, friction stir processing, ultrasonic surface rolling heat treatment, cryogenic treatment or surface mechanical attrition treatment.

These methods are often the least

highlighted in the additive manufacturing of a part – probably because some of them are still being explored at the research level. However, it is important that manufacturers keep track of their influence on the surface quality of AM components to better assess innovations at the production and performance levels.

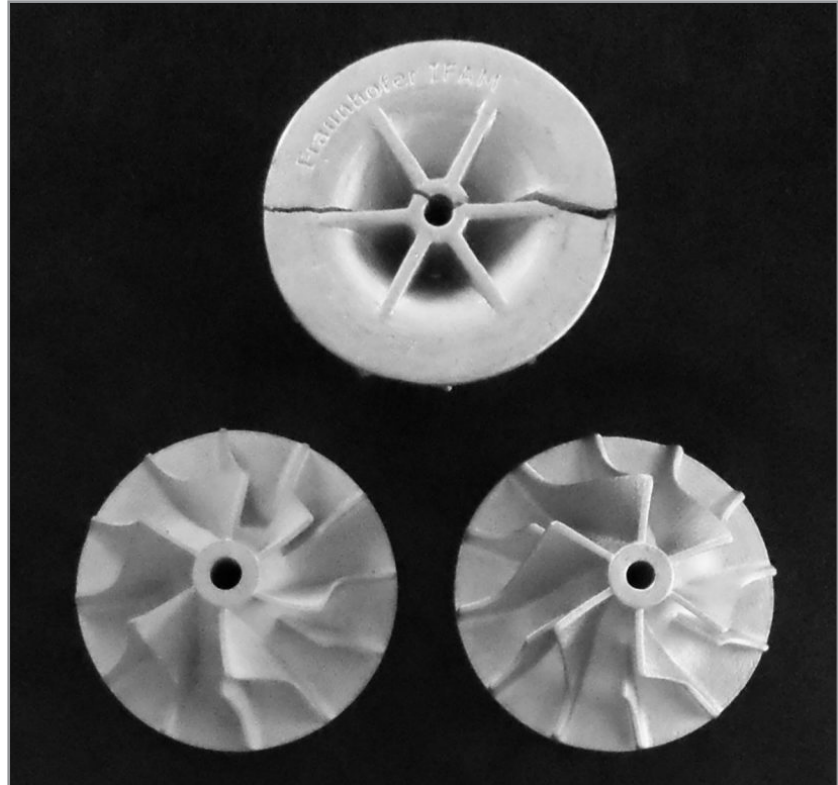
Infiltration

Infiltration is one of those operations that is only performed with specific AM processes – in this case, binder jetting or laser sintering. Binder jetting is one of the AM processes that will mostly require this post-processing task though. After the printing process, Metal Binder Jetting parts often undergo an infiltration or a sintering process.

As explained in our [dossier on the use of furnaces](#), during the sintering process, “green parts (a combination of metal powder and binder) are first heated to a temperature where the binder evolves and is removed from the parts. The furnace then ramps up to the sintering temperature of the metal which is just below the melting temperature of the material, fusing together the metal particles. After sintering is complete there is little or no evidence of the original powder particles, fabrication process and parts have very low porosity”.

As per the words of 3DEO’s CEO **Matt Petros**, infiltration comes into play for two main reasons: “*the full densification is not possible solely through sintering and high-temperature sintering can introduce extreme dimensional distortion to the part – [the ultimate goal being to improve part density]*”. In case you’re not familiar with them, 3DEO is a machine manufacturer and a parts producer that provides manufacturing services based on a [proprietary Intelligent Layering® technology](#). We have been following the company for a couple of years now and their expertise has helped us understand more than [once many of the rules AM breaks](#). In this specific case, 3DEO does not use infiltration as a consolidation step. In their process Intelligent Layering®, the parts are sintered to full density.

But, how does the infiltration process



Turbine wheels made by binder jetting, upper part broken due to high cooling rates after sintering; lower left part with significant distortion; lower right part with less distortion. Image via Fraunhofer IFAM.

work?

Once the manufacturing is complete, the component is placed in a furnace where the binder is burnt out leaving voids. The part’s density will reduce to around 60%. The operator can thereafter fill the voids left behind with bronze or another low-melting-temperature metal until it reaches at least 90% density.

Speaking of a specific process named **liquid-metal Infiltration** which can be employed as a post-sintering step to produce a fully-dense part, 3DEO’s CEO explains that “*after binder removal, a low temperature sintering step is performed to initiate necking of the metal particles. This lightly sintered part will act as a frame for the liquid-metal to fill. A lower melting-temperature infiltrant is melted and diffused into the porous network of the part via capillary action.*”

One of the advantages of this process, according to Petros, is the fact that one avoids “*extreme dimensional distortions in the part after high-temperature sintering. Any open pores within the part are filled, bolstering its mechanical*

properties and structural integrity.”

Moreover, infiltrated parts are relatively strong and have good mechanical properties, but they will be around 2% smaller after infiltration.

“One of the biggest drawbacks of infiltration is the heterogeneous nature of infiltrated metal parts. Infiltrated metal parts will exhibit properties that are difficult to predict due to the part being a composite of two different materials. Other disadvantages include increased processing time due to the additional steps required for infiltration”

Petros adds.

Those who would like to explore other methods of densification to full density can go for a sintering additive. According to Petros, the latter can help to sinter particles at a lower temperature while maintaining dimensional accuracy. “Hot Isostatic Pressing (HIP) is another popular consolidation process to achieve almost theoretical density”, he notes.

While infiltration is mostly highlighted in the manufacturing of parts through metal binder jetting, it should be noted that this post-processing step has a different meaning and understanding for those working with SLS 3D printing.

For these part producers, infiltration enables a better surface protection and gives more “stability” to the 3D printed parts. The parts are therefore protected from contaminants because they are more resistant to pressure, and waterproof.

Tracy Beard from 3D printing service bureau [Quickparts](#) explains that this post-processing method is mainly used to seal or color SLS parts. To do so, they use a vacuum impregnation process when parts need to be watertight. When a color other than the natural color of the SLS powder is required, they infiltrate or impregnate the parts with dye.

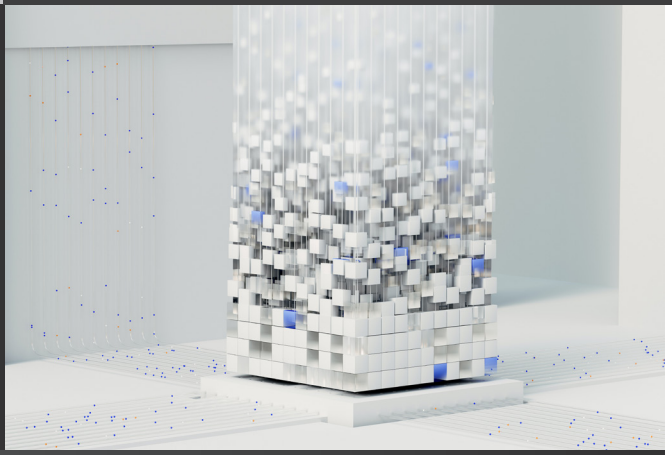
The infiltration process continues to be studied in conjunction with various thermal treatments to increase the



Sintered part, broken during depowdering due to low green part strength. Image via Fraunhofer IFAM.

strength and decrease the volatile content of the parts. Just like we saw with coating, highlighting their influence on the surface quality of AM components will help to better assess innovations at the production and performance levels.

Software






Is AI the “magic word” designed to make your product design less boring ?


In our [recap of the year](#), we observed that technology companies have been continuously working on more robust software solutions across the manufacturing workflow; software solutions that can streamline workflows and integrate with existing enterprise solutions, software that can make it easier for engineers to design a part directly for additive manufacturing rather than having to design that part twice. In this vein, software solutions are increasingly developed with the integration of Artificial Intelligence (AI). Here is the thing, there is a tendency for software companies to praise the merits of “miracle software products” with AI as a main selling point. Well, product designers should be cautious. Has AI become a “magic word” designed to make any product




look fancy, more powerful, performant or just less “boring”? When does it really make sense to say “this software powered by AI truly does wonders”? How can we avoid the media hype around this technology that still seems complex to tame? This feature aims to provide a thoughtful understanding of the integration of AI in AM-dedicated software solutions and assess the gap that remains to be filled between theory and practice.


Since [ChatGPT](#) is the latest trending AI innovation among engineers, entrepreneurs, and many social media users, we found it interesting to start our research on this topic by asking it our main question. Here is how our conversation went:




 Is AI the magic word designed to make your product design less boring?

 No, AI is not a “magic word” that automatically makes product design more interesting or less boring. AI can be a tool to enhance product design, but its impact on the final product depends on how it is used and integrated into the design process. Ultimately, the creativity, vision, and skills of the product designer play a key role in determining the success and impact of the design.  

 You only say that because your system is based on AI, right?

 Yes, as a language model developed by OpenAI, my responses are generated through AI algorithms. However, I strive to provide objective and accurate information, regardless of the source.  

 Alright, we'll also ask the same questions to AM industry insiders to see if they have a different perspective.

 That sounds like a good idea. Gathering multiple perspectives and opinions is always a good way to gain a more comprehensive understanding of a subject.  

Legend: A conversation between 3D ADEPT Media (in yellow) and ChatGPT (green).

Well, ChatGPT's responses make sense, but they are not totally accurate – our questions as well, you would tell me.

The first step in discussing this topic would be to understand how people perceive AI. If you're an engineer, your understanding of AI would probably come down to the fact that it is a [field of science](#) concerned with building computers and machines that can reason, learn, and act in such a way that would normally require human intelligence or that involves data whose scale exceeds what humans can analyze.

The problem is, there is a difference between the generally accepted definition of AI and what people truly think of it.

“When people think of AI, they think about intelligent machine introduced by popular culture, they think Star Trek, HAL 9000 from 2001 or Ultron from Avengers. We may develop technology that does all of that, but what we have today is an advance in statistical mathematics that is substantial and have a disruptive power that is reducing the cost of prediction and making it widely available”, **Dr. Omar Fergani** told 3D ADEPT Media. Fergani is the Co-founder and CEO of [1000 Kelvin GmbH](#), a software company that develops AMAIZE, an AI-powered solution that uses machine learning to predict all the issues that could arise during the printing process of complex geometries and optimizes the executable machine file to eliminate scrap, accelerate the pace of qualification and most

importantly free the engineers time for more important tasks. This software solution is at the intersection of CAE and CAM, which Fergani defines as “general manufacturing”.

By analyzing vast amounts of data, AI is said to be a valuable tool that transforms the way products are designed, from the initial spark of inspiration to the final optimization for the market. It should be noted that there are different categories of software solutions in the AM industry: **Design (CAD), Simulation (CAE); Processing (CAM), Workflow (ERP/MES), Generative Design (through the merger of CAD and CAE) and QA & Security** to name a few. So, which one of these categories is likely to be powered by AI?

“All named categories can be powered by AI”, **Daniel Büning**, CEO & Co-founder at production studio nFrontier states from the outset. Given the fact that they depend on prediction or are in essence predictive tools, they can be transformed by AI and provide either enhanced decision-making capabilities to the customer or be totally replaced by AI, Fergani adds.

To understand how AI may affect each of these categories, 1000 Kelvin's founder recommends using the framework of **Prof. Agrawal**, one of the leading AI economists:

“There are three ways we can analyze the impact of



Dr. Omar Fergani
Co-founder and CEO of 1000 Kelvin GmbH

AI: point solution, application solution, and system solution. To illustrate a point solution impact, let's take for example the quality software in additive manufacturing. Deep-learning-based image recognition systems are today capable of accurately predicting defects during the print process that even the most experienced humans cannot see. Subsequently, companies can make substantial enhancements to their quality KPIs and achieve important cost saving thanks to AI.

A great example of an AI application solution is what is happening in the field of CAE. The recent advances in the development of Graph Neural Networks (GNNs) are changing the way companies think about their CAE workflow. Simulation software is going to become a reliable data generator in the back and is fed into AI-based models making the workflow different from what we know today. These algorithms generate accurate results in seconds instead of the hours and days that are

required for traditional finite element simulations. This will have a dramatic impact on the engineering processes within large engineering organizations. AI in this case is reducing dramatically the product's time to market. Automotive OEMs who adopted this technology have substantially reduced the time of iteration between their design team and engineering team, in notorious care of heat exchange supplier moved from a 12h iteration to 15 min in total. Fast and accurate prediction enabled by AI open the door for faster optimization and decision-making. One of the most exciting impacts of AI in this field is the **expected merger of CAD and CAE to create true generative designs**. Companies like Navasto are leading the pack and I am excited to see the developments in the coming months.

Finally, the system solutions are typically the most disruptive. When AI-driven decision is part of a system, adopting AI can require an organizational redesign giving birth to a totally new system. I believe that there will be a point where AI power will disrupt traditional life cycle management software and create **industry-specific operating systems (ISOS)**. What does that mean for the AM industry? Intelligent software will be able in the future to assist companies in decision-making end to end. It will leverage generative algorithms to find optimal designs based on complex engineering, cost and timing requirements. The AI will also be capable of creating automatically manufacturing instructions to the machines and make decisions on the scheduling to the final quality reporting. These AI-enabled ISOS and their benefits will not be easy to implement like point and application solutions. However, they will provide substantial economic power to those who are adopting them from the manufacturers”.

In theory, this explanation sounds exciting and very promising. In practice, what does it look like? While the capabilities of AI are sung across every corner of the industry, there are actually very few examples of companies that highlight where exactly they take advantage of these capabilities.

Büning from nFrontier said they are currently working with the help of AI in their current project – especially in the



Daniel Büning,
CEO & Co-Founder nFRONTIER

Design field:

“We utilize AI as a front end to develop design iterations using the Open AI tools like point-e – which produce an image based on text input (called a prompt) only. Today, it is a quiet experimental workflow to go from an image created in Mind journey into CAD like Rhino (Grasshopper) – we write our own little programmes to do this. It opens up a totally new dimension in terms of creation speed and variation of design ideas.

For the CAE side, the potential to process a large dataset of image results to find the best solution for a problem is huge. In generative design – which is producing a large amount of results – feeding this into an image processor again, opens up huge potentials.

[That being said], current AI-powered solutions – like text to image – software point-e or DALL-E allow already to create an infinite amount of pictures (results) in literally no time. The vast number of results need to be checked, validated and sorted. The designer's job will be to not only feed the right input into the AI – but also to rate and choose a result which is in accordance to his preferred style. In my opinion, the job of a designer will shift into the role of a curator – that selects the right result for the task – rather than drawing something. Since you can feed a result into multiple AI's, the designer needs to know which one to use in any given situation.”

So, AI changes product design, yes. But, what are the possible positive outlooks and threats to look out for?

Product designers have a wide range of options when they want to integrate AI into their workflow. The technology can help them identify a problem or challenge, analyze the data, create concept designs, test and simulate or even optimize their existing designs.

However, they should be cautious, as integrating AI in their decision process does not necessarily mean less work for them. The more boundaries are pushed for AI-powered technologies, the more product designers should pay attention and do their best not to leave apart their creative brainstorming skills.

“The creative mind behind the monitor will have a different role – creator vs. curator. I would like to see a tool that creates printable (manufacturable) parts in seconds – independent of the input such as e.g hand drawing, photo, text, image or combinations of all”, [nFrontier](#)’s co-founder outlines.

In addition to **aesthetical issues** to keep an eye on, a crucial challenge in product design today, is **diversity and inclusivity** – which is not (always) the core of AI-powered solutions. Columnist SJ recounted [in article published by D3D](#) her recent experience with a pulse oximeter, which drives home the point that a lack of inclusive thinking in product design can have devastating consequences.

The truth is, there are various forms of AI bias, and some of them can be detrimental. In addition to data and algorithmic bias (the latter of which can reinforce the former), AI is developed by humans – and humans are inherently biased. So, the challenge here goes beyond gender and race, to encompass people with disabilities. For the product designer leveraging AI-powered tools, it’s about daring to think broadly on world issues.

From a manufacturing standpoint, **Fergani** lays emphasis on the fact that AI-powered software solutions can help designers, architects and engineers address some of the most pressing challenges of society through

two aspects:

“Today the topic of lightweight is not much addressed at a large scale yet, but AI will be able to help design and engineer lightweight structures. For example, the steel industry is at the origin of more than 8% of total CO2 emissions globally. This is massive, and a small decrease could benefit the effort for emission reduction. The usage of AI to lightweight building structures and reduce the demand for steel is one application of AI. These efforts can be extended to many other material reduction efforts, for example, to design light and circular plastic bottles that are consumed by billions every day. Thus, my hope is to see fast adoption of AI when it comes to the design of more sustainable products. But it does not stop here: new product designs need to be manufacturable, and AI can help to bridge the gap between CAE and CAM and thus pushes the boundaries of what can be manufactured.”

A look beyond the marketing buzz

AI is currently used as the main selling point by a lot of software providers and there is a great chance that most of these products do not deliver on their promise. To get over this marketing buzz, **1000 Kelvin**’s CEO recommends looking at two main requirements: **access to a rich data source** and an **application or industry expertise**.

“If we talk specifically about our industry, the reality is that most of the incumbent’s software solutions have historically not accumulated valuable data that could be used to build powerful prediction tools based on AI. Indeed, there is a lot of buzzword usage, and one should be attentive.

The good news is that more and more companies and start-ups specifically have built these AI requirements in their business model DNA. They are mostly on the cloud and have the capability to access or build rich databases. What I find as the most interesting evolution is that more and more customers are less hesitant to provide data to the service providers as these feedback data contribute to enhancing prediction and thus the efficiency of their work”,

he highlights.

Speaking of AMAIZE, and their goal of helping engineers to dramatically reduce the complexity of powder bed fusion processes to start with and make them accessible and easy to use, Fergani outlines that not only can the software solution predict the issues, but it also corrects them and generates a ready-to-use file to the customer in record time and without any infrastructure needed. It is the combination of very fast prediction thanks to machine learning algorithms, the scalability of cloud and the ease of deployment and use.

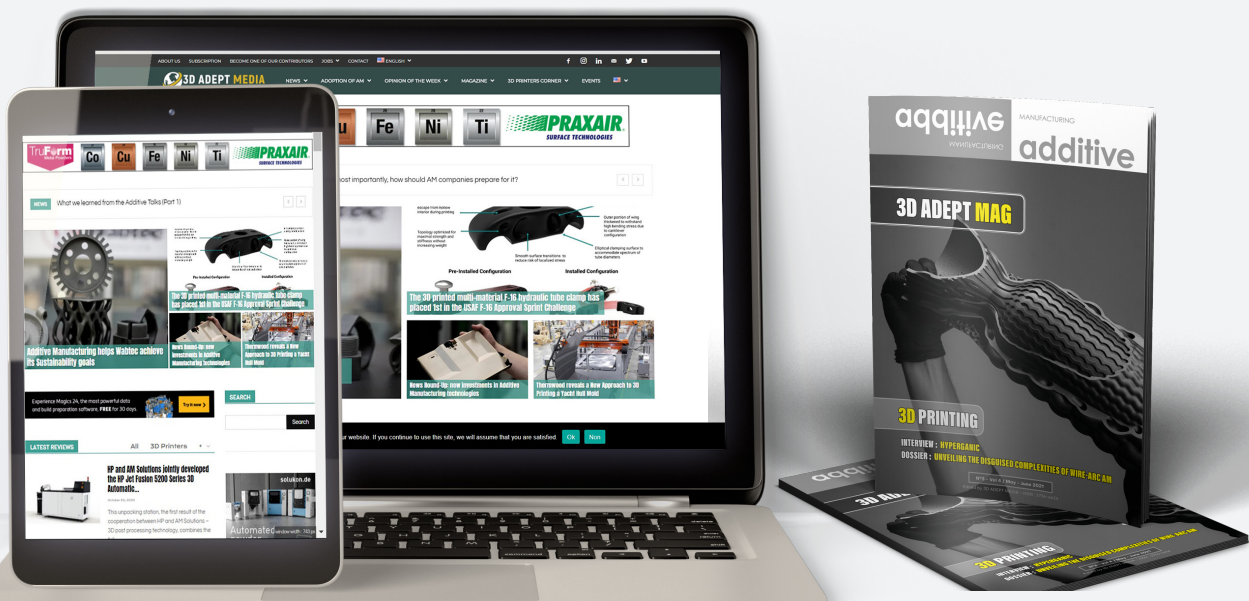
For **Büning**, it's about delivering an **added value that has been unseen so far**:

“This means the resulting design needs to be impossible to create with existing “standard” software. Open AI’s Chat GTP – creates a full text just with buzz word information at a level that makes it difficult for a human to check if an AI created it or not. The speed of these developments is really fast – it’s weeks rather than months/years in which AI’s are exponentially improving. At nFrontier, we believe in the magic of what we call “convergence”. Meaning that the innovation processes are increasingly accelerated by the technological advancements in different fields and their combinatorial twist. E.g combine AI (design) with VR (visualization/proof) and Additive Manufacturing (materialization) to come to a disruptive new product”.

Concluding notes

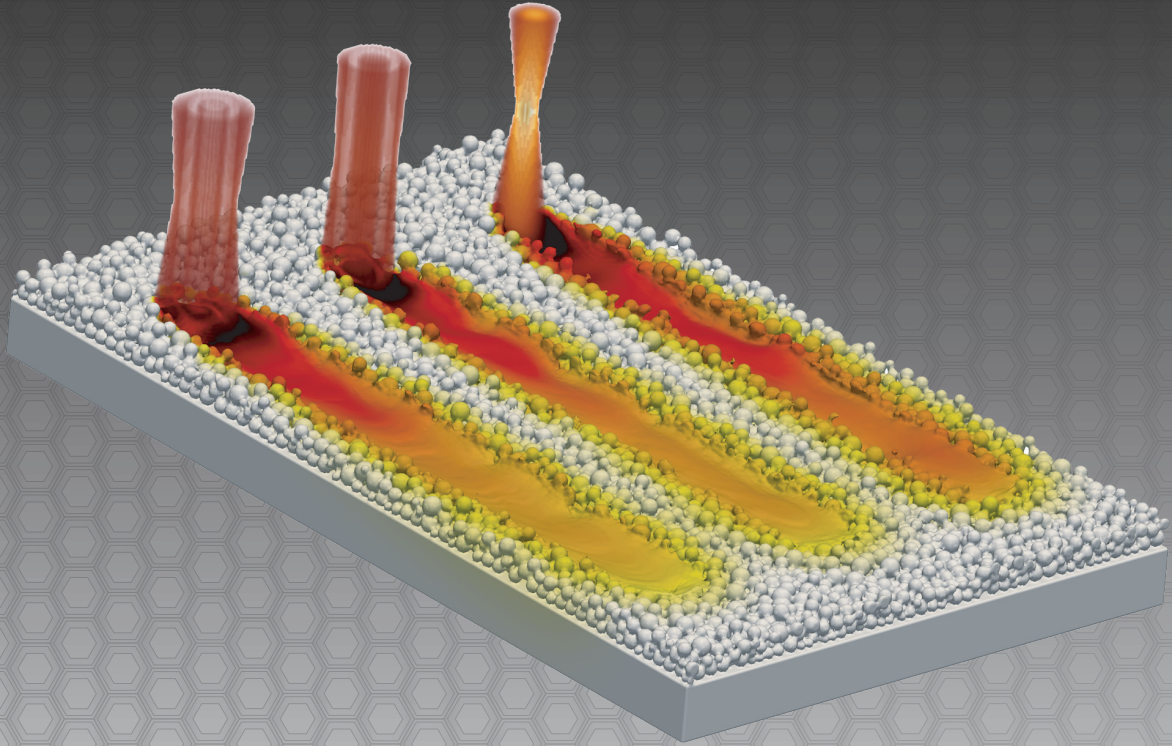
The lines above demonstrate that AI in product design goes (and must go) beyond being another ‘add-on’ to speed up processes. In fact, integrating AI to your product development workflow does not necessarily mean you will achieve the desired results. A data-strategy-first mindset is certainly required, but product designers should always bear in mind the pitfalls/limits of algorithmic bias, as it is pivotal in the development of diverse and inclusive products.

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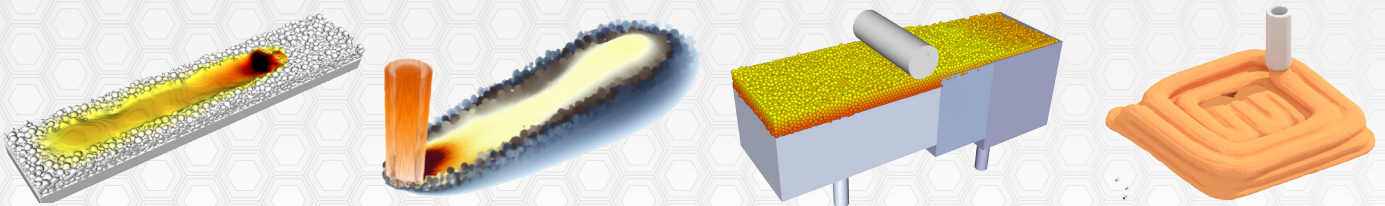
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Can ceramic Additive Manufacturing add value to the automotive and aerospace industries? From R&D to commercial applications.

As far as ceramic AM is concerned, one vertical industry where the growth potential is assured is the healthcare industry. This comes as no surprise when we know that this vertical industry is the largest and first one served by AM in general ([SmarTech](#)). With Aerospace and Automotive respectively placed on second and third ranks of vertical industries mostly served by AM, it makes sense to discuss the added value of ceramic AM within the wide range of AM processes currently leveraged in these markets.



3D printed ceramic rocket nozzles printed on the FLUX CORE printer with Low Shrink Aluminum Silicate (LS-AS) resin. Image via Fortify

The conversation around this topic comes from one observation: most of the time, Aerospace and Automotive companies are making headlines with applications achieved using FDM, metal AM, resin or polymer 3D printing. With the multitude of AM processes that are popping up every day – and taking into consideration the ones that are already commercialized –, our [assessment of ceramic AM](#) reveals a potential that is quite underestimated – or unknown? It's hard to say, quite frankly. Nevertheless, we are wondering if this lack of communication is due to a gap between technology recognition and technology usage or is it simply a matter of privacy policy between contract manufacturers and companies across the aerospace and automotive industries?

The gap between technology recognition and technology usage poses the question of how potential users see the technology. Are they seeing ceramic AM as a disruptive

technology or as an emerging one? The truth is, the words “emerging” and “disruptive” are often used interchangeably when it comes to technology while in reality, they are very different. As **Dr. Johannes Gartner**, Assistant Professor at the Johannes Kepler University Austria once [explained](#), emerging technologies describe innovations with the potential of being disruptive, real disruptions are only realized when an emerging technology is used to either solve an unsolved problem or to solve an old problem in a better way.

This means that if AM users consider ceramic AM as an emerging technology, the lack of applications in the automotive and aerospace fields might be understandable as users rarely invest in emerging technologies (fear of not achieving an ROI).

According to **Lithoz'** Director of Sales and Marketing, **Isabel Potestio**, “The main obstacle currently facing ceramic AM here is that manufacturers aren't yet fully aware of the level this process is

now at. The technology has matured significantly as a manufacturing technique over the last years –that is, while many manufacturers may have initially started using ceramic AM in a prototyping capacity, many have transitioned into full production. They have experienced the performance and workflow benefits of ceramics AM and are taking it to the next step. Today we see customers producing millions of ceramic 3D printed parts per year, which are not economically and viable for injection molding or machining.”

Furthermore, when discussing applications within the ceramic AM landscape, it's important to keep in mind that there are AM technologies designed for technical ceramics and there are AM technologies designed for traditional ceramics. The former often leads to the production of high-performance parts that usually weigh just a few grams while the latter enables the production of large molds and foundry cores that weigh several kilograms.

The wide range of applications across technical and traditional ceramics often makes it difficult to understand the specifications around technologies and materials. However, the **growing interest in technical ceramics will make us focus on this part** of the market as part of this feature.

“Ceramic machining is very challenging. For instance, in comparison to metal machining, the risk of surface damage, chipping, and tool wear are much greater, and dimensional accuracy is much harder to achieve, so additive manufacturing is arguably an even greater step forward in the field of ceramics than it is in the established fields of metal and polymer AM. Together with the unique properties of ceramics, such as strength, isolation, etc., there’s huge potential for expansion of technical ceramic applications”, **Guy Zimmerman**, Chief Marketing Officer at [Xjet](#), metal AM & ceramic 3D printer manufacturer, comments.

The lines below ambition to discuss the challenges and potential of ceramic AM across the automotive and aerospace industries.

Where do the challenges and opportunities lie within aerospace and automotive?

Whether we discuss applications in automotive or aerospace, the challenges and opportunities are reflected at two main levels:

- The materials
- The “High Value vs High Volume” decision

The materials

In general, technical ceramics are known for their contribution to a wide range of applications in the automotive industry. Whether fully electric or hybrid, high-performance parts for e-cars, e-buses, e-trucks and e-trains can be produced using technical ceramics, leading to better economy, comfort and safety. The only thing is, most of these applications are enabled by metal and ceramic injection molding.

As far as AM is concerned, one notes that technical ceramics are a great solution in critical applications where conventional materials like metals or high-performance plastics do not perform. With [8 main types of ceramic AM processes](#) identified, the choice of one ceramic 3D printing technology mainly depends on the desired characteristics to achieve – characteristics



Casting core. Photo courtesy: Lithoz.

related to material properties or resolution.

“The majority of leading mechanical ceramic applications in automotive are still made with traditional processes of CIM and Machining. The AM processes that start adding value in automotive are DLP and Direct Material Jetting. The reason is the requirement for high accuracy, repeatability and total cost per part, which requires high throughput and automated manufacturing processes”, **Zimmerman** outlines.

However, a wide range of applications is likely to pop up faster in the aerospace industry. By reducing manual assembly, and the weight of aircraft via modelling-developed designs, ceramic AM can be a great production candidate to enhance efficiency and performance. As a matter of fact, we have already witnessed the production of **nozzles, thrusters, sensors and antennas via ceramic 3D printing**.

On another note, while higher cruise altitudes and speed of flight enable better efficiency and reach, it comes at the cost of extreme environments endured by part materials. Apart from their ability to withstand such stringent environments, ceramic materials deliver increased corrosion resistance, higher stiffness, lower density, and, in some applications, multi-functional properties.

“Ceramics are the material of choice in extreme environments where other materials fail, and so it is in these applications that ceramics are really becoming commercialized. One example

is 3D printed ceramic cores for aerospace applications. With climate change being the major challenge facing the world today, manufacturers in every field are looking to be more sustainable by building more **efficient** parts to save resources. 3D printing offers a level of design freedom unachievable using conventional manufacturing techniques, allowing for the production of more fuel-efficient designs”, **Potestio** explains.

The problem is that **the difficulty that comes with creating dense ceramic materials limits the applications in this sector to the exploration stage.** Unfortunately, the latter depends on the investments that users are willing to make at the research level. However, if the research is not done in collaboration with players in the targeted vertical industries, it is in any case performed in-house by machine manufacturers and material producers.

Taking example on their solutions, Lithoz’ **Potestio** explains that each of their technology (LCM, LIS and LSD-print) answers different demands for applications across a variety of fields. For instance, Lithoz’ LIS is more suitable for coarser components and capable of large wall thicknesses and especially dark materials.

What if an opportunity lies in the ability to address a challenge that another AM process couldn’t meet?

Most applications enabled by AM usually strive to address the challenges raised by their conventional manufacturing processes counterparts. That’s the reason why you’re likely to see the comparison with a given type of traditional manufacturing process. In this case, for ceramic AM to thrive, it could be interesting to explore its ability to address a challenge that another AM process fails to address.

Vincent POIRIER, CEO of ceramic 3D printing service bureau **Novadditive**, believes that all types of ceramic AM processes can create value in the automotive and/or aerospace industries. According to Poirier, ceramic AM has a unique way to create “unfeasible” shapes with enhanced properties. That being said, the expert states that the differentiation shouldn’t be a comparison between AM processes, but rather the choice of the



Moondust (regolith) – Photo courtesy: Lithoz

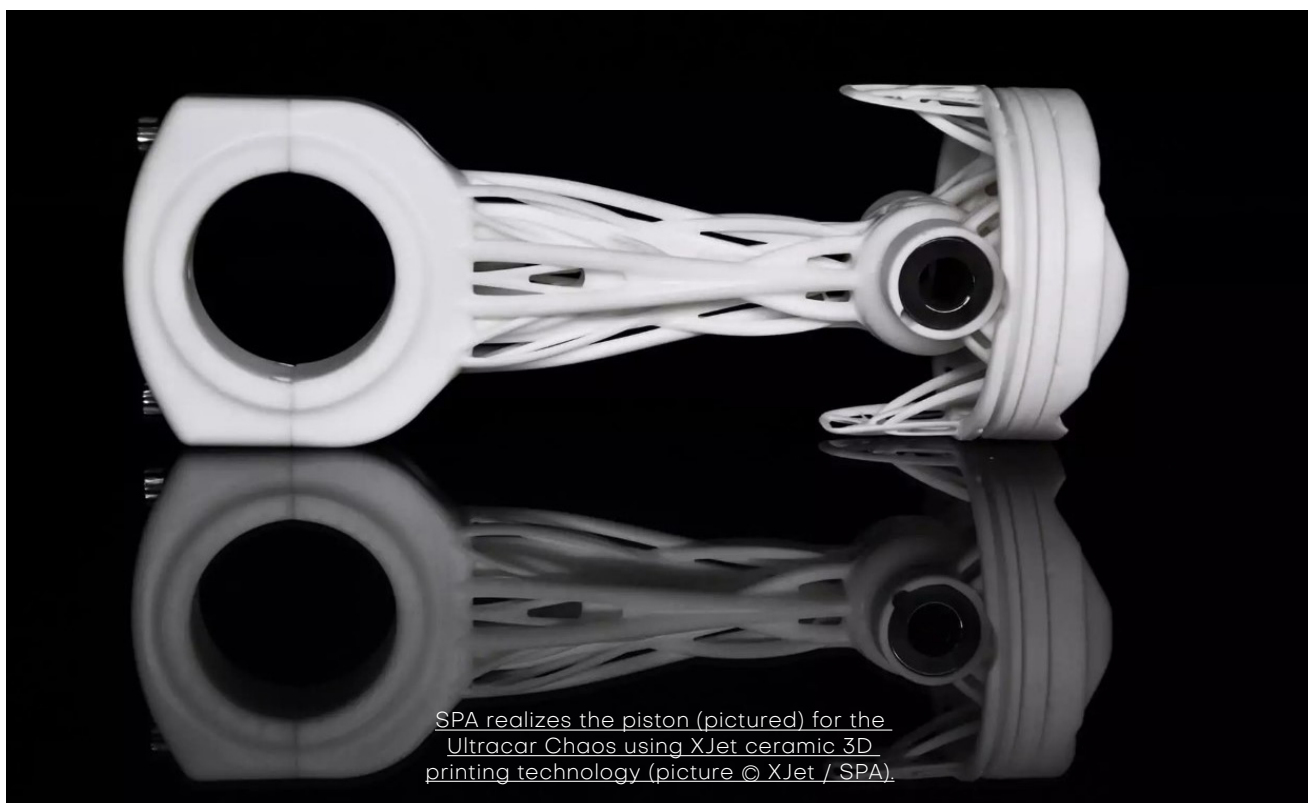
right technical material.

Among the important criteria that manufacturers should take into account to choose the ideal technical ceramic for production, one notes the **mechanical and thermal properties, stiffness** and **density** as well as the **CTE**.

The “High Value vs High Volume” reality

It shouldn’t be a decision between “quality” and “quantity” as quality must always be part of the equation. It’s rather a discussion about where the added value has mostly been seen.

In the automotive industry, for example, components require high precision and equal performance. They have to deliver excellent strength at low weight, withstand high temperatures and need to be wear-resistant to achieve high performance at a cost-effective price. Ceramic AM might eventually meet these requirements for one part but is not ready for scaling production yet. The [ceramic 3D printed piston](#) that was produced by **Spyros Panopoulos Automotive (SPA)** using the XJet Alumina material for its **Chaos Ultracar** is a great example. However, the mass manufacture of Alumina



SPA realizes the piston (pictured) for the Ultracar Chaos using XJet ceramic 3D printing technology (picture © XJet / SPA).

parts in the field has yet to be seen.

Potestio notes that, in the automotive industry, there is definite potential for innovation via ceramic AM, particularly in those applications where miniaturization and extreme levels of complexity would greatly increase efficiency. In such examples, ceramic AM can really support the development of powerful solutions for e-mobility and future wireless systems.

In the same vein, the aerospace industry is filled with astonishing examples of application cases that demonstrate the capabilities of various ceramic AM processes. Fabricating a space launch vehicle is a brilliant way to demonstrate a product's potential and high value, mass producing them with the same technology is a different battle. The reality is, the heat-resistant ceramic parts they require

are extremely difficult to manufacture. [Such parts](#) should resist temperatures as high as 2,700 degrees Celsius and drag forces of hundreds of kilograms that are encountered at speeds of Mach 5 and higher, such as on nose cones, wing leading edges and engine inlets.

At the end of the day, 3D printed ceramic parts must be affordably mass-produced, which means initial ingredients must be chosen with cost in mind. If that's not the case, then solutions should be explored to remove any unnecessary steps.

Last but not least...

Our dossier on the [current manufacturing landscape of Ceramic Additive Manufacturing](#) revealed that, with 8 main types of processes, the ceramic 3D printing market is overcoming its days of hype to focus on how it will cater to different industries' needs. This conversation

matters as the growth of AM technologies depends on an [economic perspective that should not be overlooked](#): "the more applications there are, the more materials will be developed, and the more printers will evolve or be introduced to the market". In the ceramic 3D printing market especially, understanding the gap between technology recognition and technology usage can make all the difference and open up a whole range of new applications in this sector.

FROM TOOLING TO END-USE PARTS PRODUCTION : A LOOK AT THE STRATEGY THAT ENABLES GENERAL ATOMICS AERONAUTICAL SYSTEMS TO REACH BEYOND 75% OF 3D PRINTED PARTS IN AN AIRCRAFT.

With millions of dollars already saved in tooling, General Atomics Aeronautical Systems, Inc. (GA-ASI) shares the lessons-learned of their journey with industrial AM. A meaningful example of their story relates to the completion of a lamination mill fixture production achieved in collaboration with Thermwood that led to \$50,000 in cost savings.

When you're a trade press covering the Additive Manufacturing industry, one of the milestones you are eager to see from adopters is the completion and/or installation of a production part within their operations. At that moment, you tell yourself: "We are reaching a tipping point. We are getting there, slowly but surely. It's a dream come true." We witnessed that moment for **General Atomics Aeronautical Systems, Inc. (GA-ASI)** in 2019 when the company successfully flew its first metal 3D printed component; a NACA inlet made of Titanium Ti6Al4V on an MQ-9B SkyGuardian Remotely Piloted Aircraft (RPA). While this was some of the first few milestones we witnessed, it turns out that the company's activities with AM had started nearly a decade ago and it took a conversation with **Steve Fournier** to understand the whole journey leading to it.

If you're new to this space, please note that General Atomics (GA) is a defense and diversified technologies company that develops a wide range of products such as energy systems and unmanned aircraft systems. While AM is leveraged across several GA divisions, the adoption of the technology is largely fostered by **GA-ASI**. GA-ASI is a prime contractor to the US Department of Defense (DoD), and is best known for the design and manufacture of unmanned aerial vehicles and radar systems. **Steve Fournier** who shares the company's experience with AM today is a Sr. Manager at GA-ASI's Additive Design & Manufacturing Center of Excellence.

GA-ASI's journey in AM started in the early 2010s when the company decided to explore the use of AM for RPA applications. Before investing in a specific AM technology, the company's engineering teams worked on various projects conducted in collaboration

with machine manufacturers and AM service bureaus. This way, they could learn more about the capabilities of each technology and materials before bringing them in-house. They onboarded their first AM system in 2011, a Polyjet technology from Stratasys. As its learning curve progressed, they enhanced their development application portfolio with a wide range of AM processes that followed a typical progression through FDM, SLS and then metal AM technologies.

Using more than seven different AM process modalities for multiple applications today, GA-ASI continues to invest in several elements essential to the growth of their AM landscape to serve GA-ASI's products and customers. Specifically, GA-ASI has invested a lot of resources in facilities infrastructures, in a rapidly growing team of Subject Matter Experts (SMEs), in AM equipment as well as in R&D in order to reduce risks at multiple levels related to materials, processes and applications.

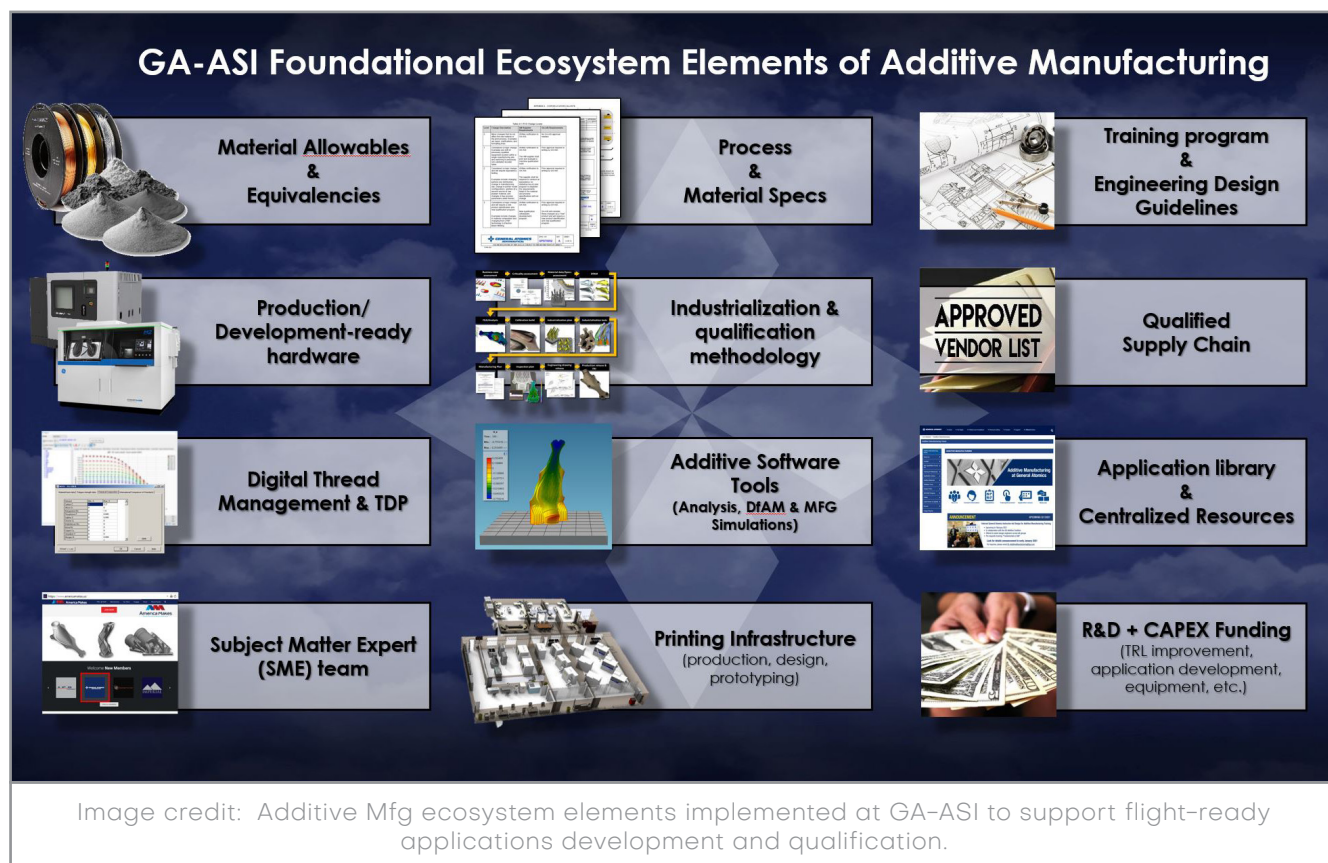
This means, for instance that, for **rapid prototyping purposes** (non-flight), GA-ASI have developed multiple resources internally, including the AM group supporting engineering that leverages most of the AM technologies, whereas for **manufacturing operations** of flight-ready product development and production parts, FDM, SLS, metal-LPBF, DED-W, BJT and LSAM/BAAM will be more indicated. Needless to say that these technologies are supplemented by engineering design (DfAM) capabilities, post-processing equipment, material conditioning and testing, inspection or metrology infrastructures.

"With nearly 7,000+ parts 3D printed per year, we have over 320 different SKUs that are flying today across several of our aircraft platforms, representing over

300,000 accumulated flying hours. That represents a mix of polymer, composite, and metal parts. The military RPA market, with its high mix, low volume model, is a perfect area of the aviation industry to introduce AM. Back in 2011, we started building up our infrastructures and brought in our first printers, etc. Back then, it was mainly for prototyping applications to help us explore

the materials and the potential areas for its applications on our products. In 2016/2017, GA-ASI leadership recognized the value and need to build a team of AM SMEs, and in 2018, a formal department was created. We started with only four people, and now, we have 14 people dedicated to AM technologies. One of our main areas of focus was to develop the structure of our strategic

roadmap composed of an **AM technology ecosystem** to help us transition from prototyping to a production-ready operation and help drive its implementation across the organization in order to go after multiple applications. Thermwood's LSAM is just one of the technologies that enables us to achieve that goal," Fournier recounts.



After building a solid AM team and strategy foundation, GA-ASI then opened the company's Additive Design and Manufacturing Center of Excellence (AD&M CoE) in 2021. The Center focuses on rapid-reaction manufacturing serving GA-ASI's line of Unmanned Aircraft Systems (UAS) using fully functional and flight-ready Additive Manufacturing (AM) applications. In addition, they support research and development for applied risk reduction purposes related to large-scale tooling, existing and next-generation flight hardware.

While GA-ASI conducts a wide range of recurring production activities at its AD&M CoE, Fournier outlines the fact that **the demand for in-house rapid-reaction and low-rate manufacturing** for early phase lifecycle development programs has required them to rely on a strong AM manufacturing supply chain for the overflow production of complex end-use thermoplastics and metal parts.

Speaking of the purposes these infrastructures serve through their 8,500 square feet (790 m²) Center of Excellence, Fournier explains:

"We leverage rapid manufacturing capabilities to respond to low to medium volume requests on metal, composite and thermoplastic fully functional parts (form, fit and function). There is a distinction between prototyping and rapid manufacturing in the depth of qualification efforts required for the two different type of use of AM. The latter requires qualifying the materials, the technology and reducing all application-related risks through engineering substantiation.

The second area of interest is R&D. We invest in materials and processes to qualify applications for each AM technology of interest. For instance, over the past several years, we invested significant R&D resources to qualify tooling applications using Large

Scale Additive Manufacturing (LSAM) technology, which is now part of our production portfolio. The R&D is really application-based and we keep a close look at the near-to-medium term return on investments (ROI).

The third aspect of our work is about recurring production. We do build plastic and metal parts that go directly onto aircraft after an extensive quality assurance process. We keep between 15% to 30% of our production demand in-house to maintain our production-level processes and skills, and we leverage our qualified contract manufacturers for our overflow production needs. And that outsourced production keeps increasing. Our main goal is to achieve rapid-reaction manufacturing using multiple AM technologies, bring

applications from a “one-off” to a recurring level, and fortify our supply chain to support our fast AM growth.”

A portfolio of applications enabled by AM

While our interest in GA-ASI’s adoption of AM has been raised on the heels of a use case achieved with **Thermwood’s** LSAM technology, our conversation with the company’s representative reveals how they have developed several families of applications with AM technologies. These families of applications include for instance: conformal structures, air management ducting and manifolds, covers and panels, engine and exhaust components, mill fixtures, ultralight structures, lamination tools, OML components and heat exchangers. These are just a few examples we kept

from our conversation with Fournier. Many more are being explored right now.

No matter what the application is, the team at GA-ASI always kept in mind three things:

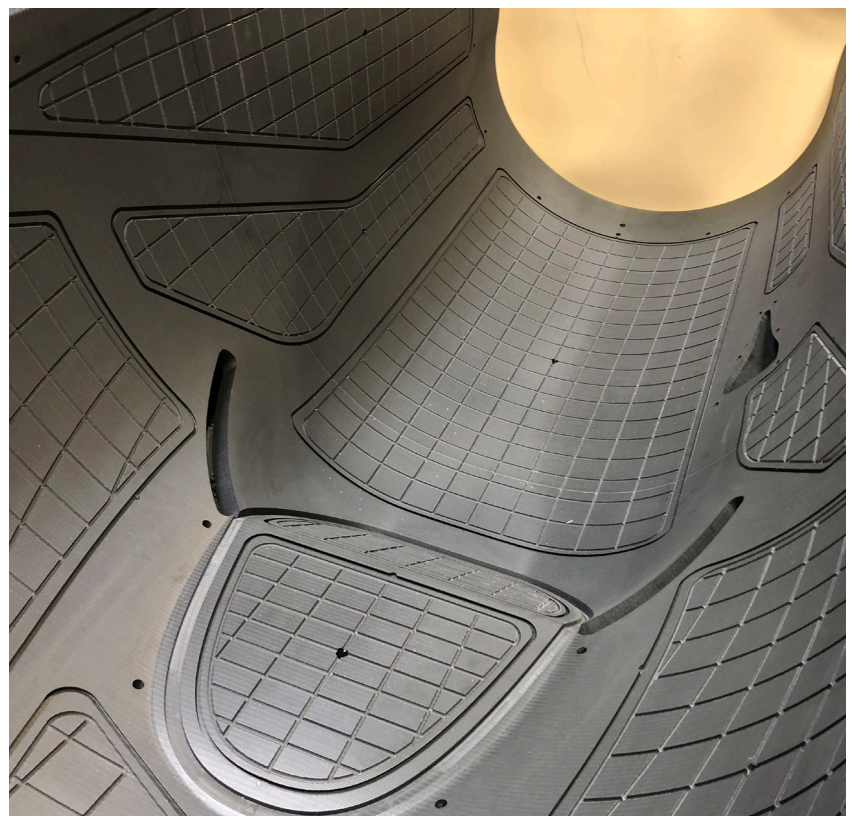
- It’s of paramount importance to ensure a valid business case before “going all technical” (“**printing because we should, not because we can**”);
- The intended manufacturing goals (is it for prototyping or production purpose? It’s crucial to differentiate between these two goals as they will require different qualification efforts);
- And the technical requirements which drive the choices of the right combination material, process and design approach.

The case of the lamination mill fixture production achieved in collaboration with Thermwood

If you’re a regular reader of 3D ADEPT Media, you probably know that Thermwood is one of the rare companies providing very large format 3D printing hardware and services with composite chopped Fiber Reinforced Polymer (FPR) pellet materials. With an [increasing portfolio of machines](#), the company partners with a wide range of material producers, industrials in vertical industries adopting AM and academics to explore applications that could lead to viable business cases for its Large Scale Additive Manufacturing (LSAM) technology.

Speaking of the CNC trim tool/fixture, **Scott Vaal**, LSAM Product Manager at [Thermwood](#), explains that it “is typically used to hold a 3 dimensionally formed plastic or carbon fiber composite part for secondary trimming operations such as final perimeter shape and holes and cut-outs. Parts are commonly held to the fixture using vacuum or a combination of vacuum and other mechanical holds down”. “Several traditional methods [are often] used to make CNC trim tools/fixtures, from gluing up blocks of various

materials and machining it to shape, pouring a cast type material on the back side of one of the untrimmed parts, and metal or even wooden support structures used by themselves or in conjunction with the poured or glued up



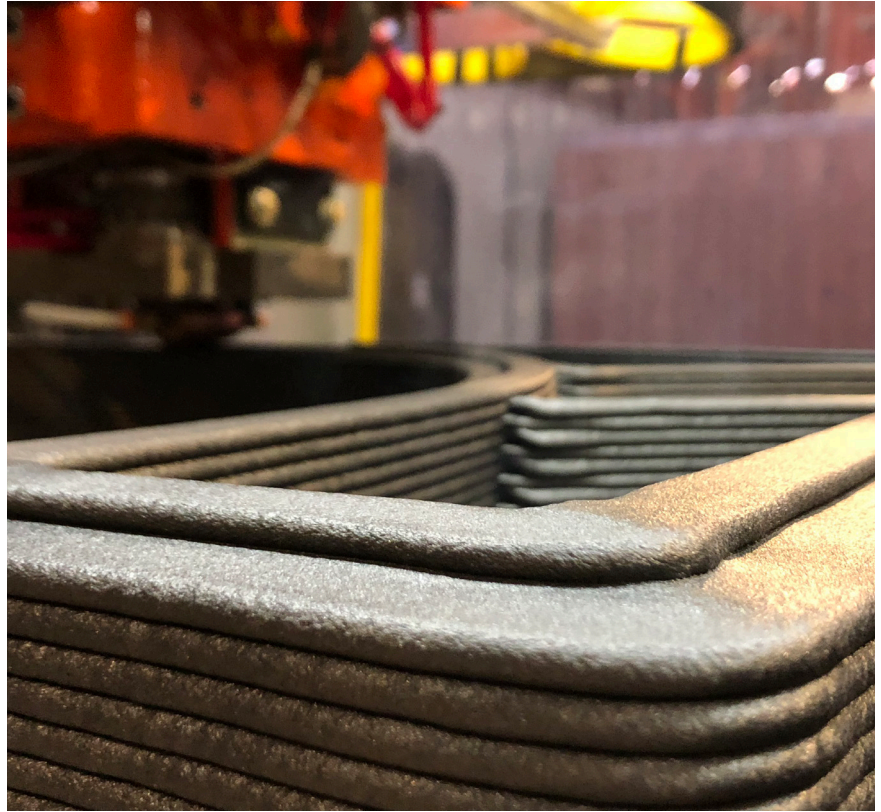
blocks method,” he adds.

According to Fournier, the development of a lamination mill fixture tool using AM processes originally came from the fact that they wanted to explore **the technical feasibility of making such a tool cheaper and faster:**

“We started in 2017/2018 by selecting a couple of R&D projects related to this type of tool (room temperature lamination fixtures). The main challenge at the time was to find a toolmaker who had the technology to explore the application. Although we initially started by working directly with Thermwood application team, we started soon thereafter working and qualifying toolmakers who are using Thermwood’s technology.”

Given the price of the 3D printer, it was risky for GA-ASI to start by investing in a technology with no certainty that it would deliver on the business cases they wanted to build. Not to mention that, once you get the 3D printer, you need to have a qualified workforce that could operate the machine, all the pre- and post-processing equipment that could help deliver the desired part, as well as the right facilities to host this type of large-size equipment.

“Given all that, it becomes pretty capital-intensive for most companies to get into this technology. That’s why our strategy was not to buy a printer right away but rather to develop our supply chain partners. Developing and qualifying the application helped us to **create the “demand signal” for the applications that could be met** by potentially insourcing this technology at a significant infrastructure and resource cost. After convincing ourselves that the technical requirements could be met for the mill fixture tooling



applications, we have since expanded our usage of LSAM technology beyond the tooling use cases, and are continuing our investment into our supply chain,” Fournier explains.

The exploration period for this business case took about 2–3 years. It was marked by a lot of testing and manufacturing trials before they concluded it was a viable tool for production. The 3D printing process itself of the mill fixture took about 16 hours and required the use of a **Thermwood LSAM 1200** which processed an **ABS material (20% Carbon Fiber filled)**. The post-machining process of the critical tool surfaces took significantly longer. Overall, the process delivered a final tool that weighs **1190 lbs (540 kg)**.

“The LSAM is available in many models, sizes, and configurations to fit a variety of needs. Each LSAM is equipped with the same unique and patented Melt Core system which can process and print a wide variety of materials that can be used for room temperature applications all

the way up to high temperature materials that can be used for aerospace autoclave tooling that must exceed 350 degrees Fahrenheit [177 °C]. To date, we are unaware of a practical material that the LSAM cannot process and print”, **Vaal** reminds us before commenting on the production: “this part was pretty straightforward on the printing side of things and lent itself very well to the process. The only real challenge was on the 5-axis CNC router side of things. There was not enough router head clearance to be able to machine some seal groves on an approximately 2” wide flange on one end of the part. So, we ended up splitting and printing the flange section separately so we could machine the flange and groves easily and then bond it to the main section accurately using dowel pin locating holes to finish the part.”

Interestingly, this application is said to have enabled GA-ASI to **save costs of around \$50 000 (€46,192) vs traditional methods.**

Calculating these cost savings can be quite simple nowadays: “for tooling applications for instance, one can get quotes from multiple vendors of both conventional and additive options, and make the comparison from there. The design aspect of the work can sometimes be a significant difference in the quoting process however. Over time, you accumulate enough statistics on multiple tools geometries to start getting a metric of cost per tool face sheet surface area. This is a typical metric used in the tooling industry. It is important to note that these business cases can differ wildly depending on tool geometries.

Not all tools are best suited for LSAM technology. Machine manufacturers on the other hand have a different way of calculation because they need to take into account the depreciation of the machine, the staff required, the materials, etc. but they essentially come down to a dollar per pound or square footage,” Fournier outlines.

Fast forward to today: going beyond mill fixtures with Thermwood’s LSAM

Today, GA-ASI has grown a cross-functional team of subject matter experts on the technology within multiple engineering, quality, procurement and manufacturing functions, and they continue to invest in this technology in order to reduce additional technical and business challenges encountered as they push further the application space for this technology.

“Today, we are doing both tooling for large room temperature mill fixtures, exploring higher temperature applications, and also some end-use parts for very large structures. Each application comes with its share of challenges,” Fournier emphasizes.

“We are also pushing our exploration towards the higher temperature side, with lamination tool. For such applications, one of the very significant and limiting challenges of this technology is the CTE”, he notes. [Coefficient of Thermal Expansion = describes how the size of an object changes with a temperature change. In other terms, the material property is indicative of the extent to which a material expands upon heating.] Put simply, and without digging

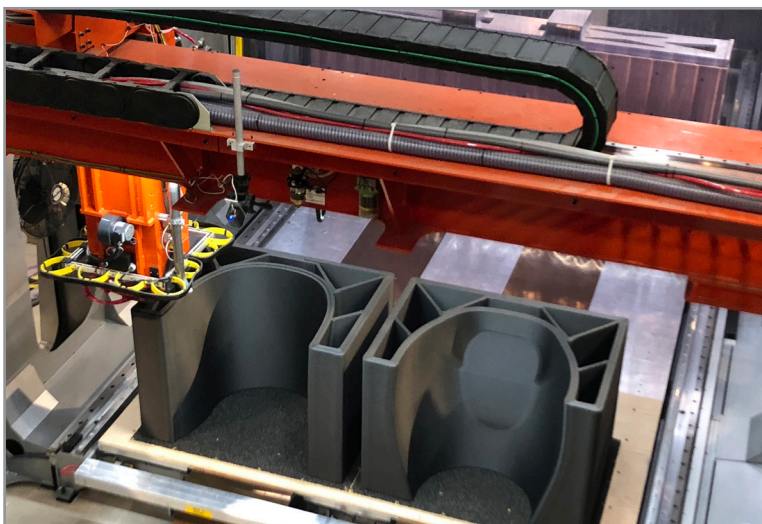


Image credit: Thermwood; LSAM printer printing sections of a large scale mill fixture tool

too much into technical details, the anisotropic nature of the printed material properties creates lamination application issues. For instance, the thermal expansion along axis XY plane is very different from the one measured along the Z axis. This leads to potentially significant lamination issues on tool and part integrity, depending on the temperature ranges and tool face geometries.

“Because of the anisotropic properties, for some lamination tool geometries, the LSAM technology brings significant challenges in the tool design to pre-compensate and control the tool shape during thermal cycling, as well as for the demolding process which can impact the laminate part integrity itself. In the end, the technical risks MUST be balanced with the benefits brought by the manufacturing technology used. This particular technology is good and beneficial for room temperature applications. Even at room temperature, the application space is limited to a certain class of tool geometries and end use structures. With the partnership of our supply chain partners, we are now pushing the boundaries of the application space to see what can be beneficial– from a business standpoint”, he completes.

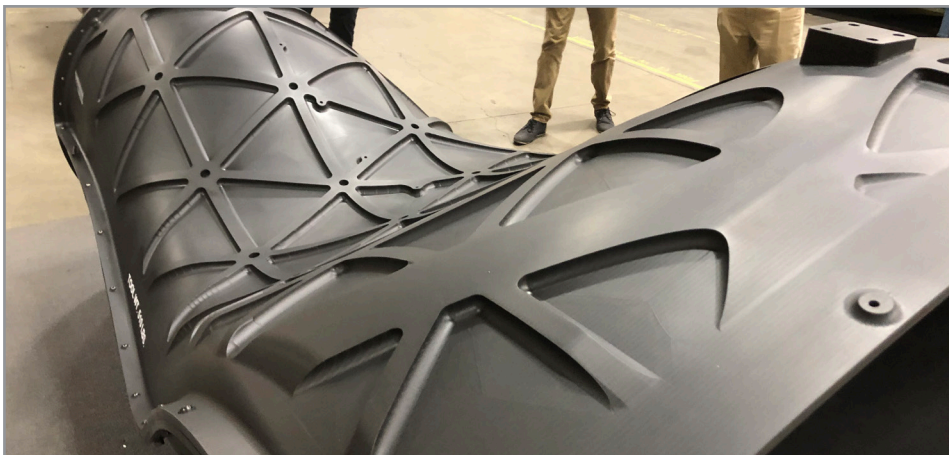


Image credits: End-use large components using LSAM technology.



Image credits: GA-ASI. Large scale functional structures are pushing the limits of the application space for large scale thermoplastic AM technology.

The journey continues

The implementation of AM technologies within the aviation and defense industry is a long journey that continues “one application at the time.” Through his 15 years of experience with AM, Fournier shared a few of his learning:

- Each industry, and each user within a given industry have specific application sets, and it is important/critical to identify the business benefits at the aggregate level to help motivate the investment of capital and resources to bring AM to the level where those benefits can be realized

- Many AM technologies have reached an industrial level and can be used for production-ready applications with proper and sufficient controls. Others require further establishment of AM ecosystem elements such as standards and better equipment engineering. But AM should not be the end goal. **AM is a powerful enabling tool in a large toolbox** which it combined with conventional technologies as well. The key to success is to find the right

applications for AM.

- It was beneficial to GA-ASI to invest in building a team of SMEs ahead of investing in infrastructure and equipment to build a strong roadmap AM ecosystem and establish its value propositions.

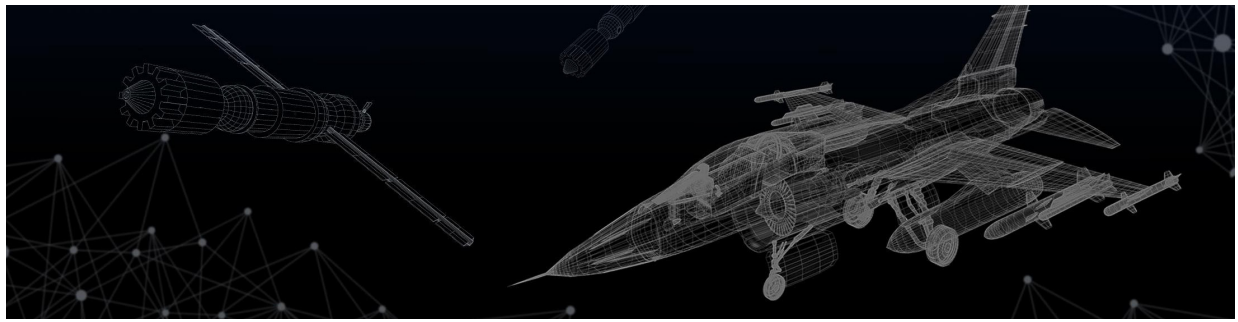
- AM use cases can be summarized in order of growing value proposition by **a)** part substitution to achieve component-level benefits **b)** part consolidation to avoid assemblies and associated costs implications, leading to **c)** novel and uniquely enabled design for AM (DfAM) solutions, which may rise to the sub-system level. As well, sustainment solutions are not to be underestimated in the later phase of our product lifecycles.

“Typically, I describe AM as a “luxury car” technology analogy... When we consider new applications for AM, we always ask ourselves: why AM? Using a “luxury car-level technology” requires finding an equivalent high level application and benefits. This means for us at GA-ASI more parts integration, even better performance designs, and manufacturing

cost reduction. Achieving that generally will require creating new more complex designs that conventional manufacturing processes will increase in cost and tooling requirements, whereas AM will be able to handle such complex design with little-to-no cost difference, and often, without the need of any tooling. It’s about using AM for the good reasons,” Fournier concludes.

GA-ASI has already been able to save millions of dollars in non-recurring tooling and save very significant recurring cost on their aircraft platforms. As they continue pushing the boundaries of the applicability of various AM technologies and exploring new applications, they anticipate being able to achieve more parts integration, and over time, increase the % of AM content on their aircraft platforms from <1% up to 75% depending on the class of aircraft and its survivability level, avoid tooling when possible in the manufacturing process of their components, as well as helping to bring novel AM tooling solutions when required.

Additive Manufacturing for Aerospace, Defence, & Space



The aerospace industry is continuously evolving, and the introduction of additive manufacturing (AM) has revolutionised the industry. AM is rapidly revolutionising the aerospace, defence, and space sectors, and is transforming how products are designed, manufactured, and supplied. It has the potential to significantly reduce production costs, improve product quality, and reduce lead times. The aerospace industry is now embracing this technology and is actively pursuing ways to integrate it into its production processes.

AM has a number of benefits for the aerospace, defence, and space industry. It enables manufacturers to reduce production costs by eliminating the need for costly molds and tooling. It also allows for rapid prototyping and testing of components, enabling manufacturers to quickly identify design flaws and make necessary modifications. Additionally, the technology enables manufacturers to

produce complex components with intricate geometries that would otherwise be impossible to make with traditional manufacturing methods.

The future of AM for aerospace, defence, and space is very promising. As the technology advances, manufacturers will be able to produce more complex components with greater precision and faster lead times. Additionally, the technology will continue to become more cost-effective, making it accessible to more manufacturers.

Defence iQ's Additive Manufacturing for Aerospace, Defence, & Space conference is returning for its ninth iteration at the Hilton London Wembley, UK from 22-23 February. In recent years it has firmly established itself as the premier forum for AM users, R&D experts, and industry partners within the aerospace, defence, and space industry. It is the leading conference platform for ensuring opportunities in high-value manufacturing are secured to ensure that the

aerospace, defence, & space industry is prepared to confront the challenges of wider AM adoption and development.

The conference provides an invaluable platform for industry professionals to share their knowledge and insights on a wide range of topics related to additive manufacturing. Additionally, it provides a platform to support opportunities in high-value manufacturing and help prepare the aerospace industry to tackle the roadblocks of wider AM adoption and for attendees to network and discuss the latest trends, challenges, and breakthroughs in the AM sector.

Over two days, the conference will host keynote presentations, panel discussions and roundtables to facilitate discussion and collaboration within the industry.

Make sure you are part of the conversation this February. To see the full line-up of speakers, sessions, and more, [download the 2023 agenda here](#)

BENEFITS OF ATTENDING:

1. Network with industry experts and professionals
2. Hear key case study presentations demonstrating the latest achievements and lessons in AM
3. Discuss the future opportunities and potential for AM in the Aerospace & Space sector
4. Leverage emerging technologies in process monitoring to maximise quality

KEY SPEAKERS INCLUDE:

- Dr. Melissa Orme, Vice President, Additive Manufacturing, Boeing
- Richard Hamber, Team Leader HVM CoE, Future Capability Group, DE&S – UK MOD
- Jenny Manning, Head of Additive Manufacturing, BAE Systems
- Mark Benedict, AM Lead, Air Force Research Laboratory
- Thomas Rohr, Head of Materials and Processes Section, European Space Agency

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AM EVENTS



35 years of AMUG: the how and the why of a volunteering commitment that pushes the AM industry forward

The 2023 edition of AMUG will be held at Hilton Chicago, from March 19 – 23, 2023.

If you're a Communication & Marketing Manager new to this industry and trying to set out your events agenda for the year, there is a great chance that you get recommended AMUG, the **Additive Manufacturing Users Group**. Held in the USA once per year, the conference ambitions to educate and advance the uses and applications of Additive Manufacturing technologies but not in the usual way, in an "open space" style, as the event is **designed by users and for users**.

The story goes that AMUG started in 1988 with just a handful of people meeting to share knowledge of 3D Printing. At the time, the founding industry users group was called 3D Systems North American Stereolithography Users Group, users group solely focused on the advancement of stereolithography (SL) use with the owners and operators of 3D Systems'

equipment. Today, AMUG educates and supports users of all AM technologies. And the best part is, while AM companies can provide support in the organization of the event, this "open space" style has allowed users to shape the development of hardware, software, materials, and applications based on their needs.

As an AM and User-centric event, I do not doubt AMUG is fulfilling its mission. I mean, that's one thing, one should all recognize after 34 editions of playing host to industry professionals from various vertical industries adopting AM technologies – this 2023 edition being the 35th one – but AMUG seems to be one-of-a-kind type of event, and its uniqueness may be the secret ingredient to its success: **volunteering**.

Volunteering, a tradition and a passion

It's hard to talk about volunteering after a

couple of pages that discussed fundraising and bootstrapping (See pages 12 to 15). It's hard to talk about volunteering in an industry or a world that is fostered by capitalism in short. Surprisingly, this secret ingredient of the AMUG sauce seems to be a "contagious disease" people get, the first symptom being a passion to serve people. Our conversation with **Mark Abshire, AMUG President**, confirms it:

"My first experience attending the AMUG Conference as a user was in 1991. It was truly an open environment where users discussed everything from basic part orientation to the advanced algorithms involved in part-building parameters. But the most important assets I walked away with were the relationships developed with others in the same industry-- friends I could rely on for solutions and advice to get the most out of my

AM equipment.

By 1994, I was participating as a speaker and had entered the Technical Competition. In the following years, I served on the board in various positions, including Vice-President, Secretary and Registrar.

Moving from just an attendee to being a part of the conference is an evolutionary process for many of our members. While viewing conference presentations, you realize that you have some knowledge and experience worth sharing, so you submit an abstract, become a presenter and now you are a participant. Or perhaps it is entering the AMUG Technical Competition with the opportunity to display your expertise to your peers. The next step is to commit a little more time as a committee member. And utilizing these experiences can easily grow into a leadership contribution as an AMUG Board member.”

Abshire who shares this experience today is one of those people we call the veterans of AM. He started his career in the field three decades ago and right before that, he worked in the ‘subtractive manufacturing’ arena as a machinist/toolmaker.

It may be hard to believe, but you don’t decide on a whim to volunteer for AMUG. As a matter of fact, it requires a certain expertise in the industry and patience – depending on the committee that raises one’s interest.

According to **Abshire**, apart from the Board of Directors which consists of volunteers elected by the membership, members have to submit a form and rank three committees where they would like to serve.

“We have an abundance of volunteers each year and most get their first choice, but unfortunately, with a plethora of volunteers, not all submissions can be placed. We try to limit the number of committees that a person can serve on so that we can include as many individuals as possible. In addition, I challenged our committee chairs to fill their teams with at least 25% that have not been on their committee in the past. Our committee chairs excelled with almost 30% of our committees filled with members serving in new roles. This new participation brings fresh ideas and new skills”, he explains.

In figures, what does it look like?

Today, AMUG is 10 volunteers serving on the Board of Directors, supported by over 100 members who volunteer to serve on



Mark Abshire, AMUG President

20 committees – The committee members serve for a year in areas directly related to the conference and the organization. Other opportunities are given to people who would like to serve onsite during or prior to the conference.

An excellent example of onsite volunteers, as per the words of Abshire, is individuals with fishbowls of numbers at the door to lunches. Each attendee will pull a random number from the fishbowl, which specifies where they will be seated. This creates a valuable networking experience by providing an opportunity to meet new people daily and expanding personal networks with those with similar interests and experiences.

What about technology, you may ask?

Well, with the ability to share openly, the good, the bad and the areas for improvement that may help AM technology providers enhance their solutions, the past decades reveal an evolution in three phases in the adoption of AM technologies.

According to the organization’s President, “when 3D Printing began, the primary

use was 'Form' to convey an idea. As machines, materials and software advanced, a level of accuracy allowed us to include 'Fit' as an application. And over the last few years, new materials introduced have allowed us to include 'Function.' AM is now on the cusp of mainstream manufacturing that requires the trifecta of Form, Fit and Function. The next generation will advance these basics in the next three decades, and AMUG considers itself an integral part of training the next generation for these challenges".

A big part of this transformation is seen through a rich agenda that is continuously adapted to feature topics ranging from technology basics to advanced applications to business considerations. For this 2023 edition, for instance, key highlights of the program include:

- Keynote speeches
- o Collaborations Between an Animator, an Architect,

and a Surgeon: The Keys to Impactful Innovation in Medicine by Rob Ducey (LAIKA) Studios and Nicholas Jacobson (CU Anschutz Medical)

- o High-Performance, Low-Cost Liquid Propulsion Enabled by AM by Max Haot (Launcher)

Robert Ducey of Laika Studios and **Nicholas Jacobson** of the University of Colorado's Anschutz Medical Campus will take the floor on Tuesday, March 21. They will unveil the results in innovative designs for pediatric epilepsy, cardiology, and cleft palate and share lessons learned as part of their collaboration.

Max Haot on the other hand, will present on Thursday, March 23. One may expect an interesting look into his company's E-2 liquid rocket engine.

Other highlights of the program that are worth mentioning include:

- Innovators Showcase, including presentation of

the Innovators Award.

- 2022 Technical Competition Winners Presentation
- 2023 Technical Competition Winners announcement

The full agenda remains available via the [AMUG website](#).

So, yes, after 35 years, Users continue to drive the advances, innovations and applications.

"AMUG is only a collection of these users that have propelled Additive Manufacturing to the forefront of almost all Industries over the last 35 years. The AMUG Conference is where AM users network with AM manufacturers to identify the hardware, software and materials that are needed in multiple industries. Expect AMUG to continue to be a driving force that amplifies the voices of the users to bring new products and applications forward", Abshire concludes.

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March 19-23, Chicago, IL, USA

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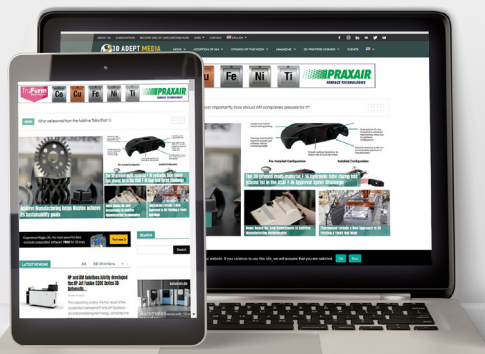
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2023 EVENTS

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EBAM CONFERENCE 22-24 MARCH, 2023	ADDITIVE MANUFACTURING STRATEGIES 2023, 7-9 FEBRUARY, 2023	TCT 3SIXTY 7-8 JUNE, 2023
HANNOVER MESSE 17-21 APRIL, 2023	AMUG CONFERENCE MARCH 19 – 23, 2023, HILTON CHICAGO	THE ADVANCED MATERIALS SHOW 28-29 JUNE, 2023
RAPID.TECH 3D 9-11 MAY, 2023	RAPID + TCT 2-4 MAY, 2023	VEHICLE ELECTRIFICATION EXPO 28-29 JUNE, 2023
	SPAIN	THE NETHERLANDS
AM FORUM BERLIN 4-5 JULY, 2023	ADDIT3D 6-8 JUNE, 2023	3D DELTA WEEK 27-31 MARCH, 2023
EMO HANNOVER 18-23 SEPTEMBER, 2023	METAL MADRID 15-16 NOVEMBER, 2023	
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FORMNEXT 2023 7-10 NOVEMBER 2023	EURO PM2023 1- 4 OCTOBER, 2023	GLOBAL INDUSTRIE 7-10 MARCH, 2023
MEDTECLIVE 2023 23-25 MAY, 2023	AM SUMMIT 2023 COPENHAGEN	PARIS AIR SHOW 19-25 JUNE, 2023
MORE EVENTS WILL BE ADDED LATER !		

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