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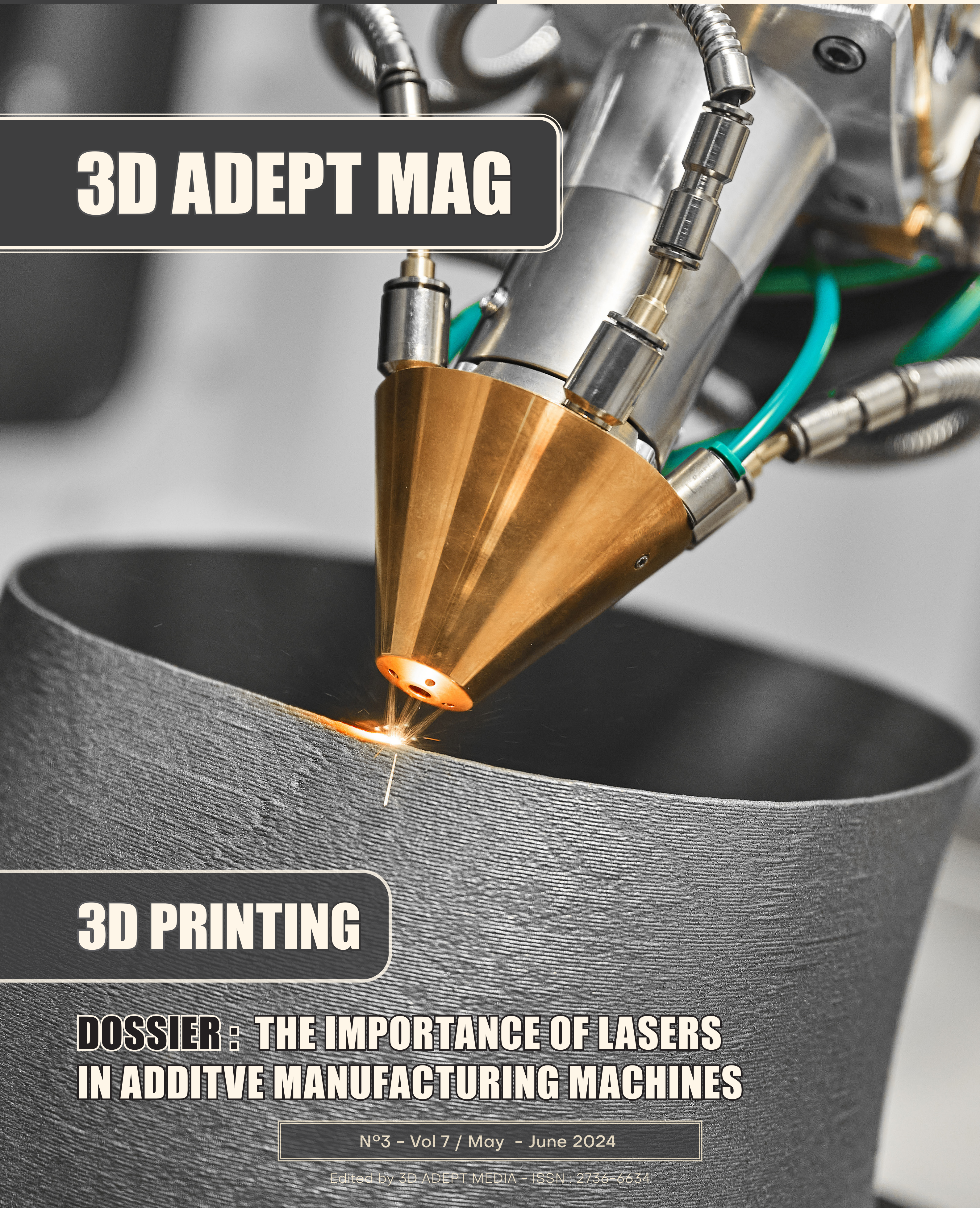

3D ADEPT MAG

3D PRINTING

DOSSIER : THE IMPORTANCE OF LASERS IN ADDITVE MANUFACTURING MACHINES

N°3 - Vol 7 / May - June 2024

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

Edited by 3D ADEPT Media

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Periodicity & Accessibility:
3D ADEPT Mag is published on a bimonthly basis as either a free digital publication or a print subscription.

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All about Additive Manufacturing

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HELLO & WELCOME

Improving Additive Manufacturing with existing technologies

Have you ever realized that sometimes (or most of the times), some people often seek drastic changes or new beginnings, believing that only the new can bring fulfillment and success? Yet, a personal experience recently made me realize that true growth and improvement often lie in refining and optimizing the aspects of our lives that we already possess. Think of it for one second: enhancing existing skills, nurturing current relationships, and making incremental improvements in our daily routines can all lead to profound and lasting positive change.

Unconsciously, we often apply this concept to the Additive Manufacturing world; a world where the allure of new technologies overshadows what already exists. The ultimate goal being to help AM users refine and improve their current processes, we assess the foundation of previous efforts (hear "technologies") and determine what strengths could be leveraged to deliver better 3D printed parts.

"The importance of lasers in AM machines", "The different ways AM connects to (CNC) machining", "The imperative of cybersecurity in Additive Manufacturing" and "Mom was wrong. You should put metal in the microwave; it won't go bang!" are just a few examples of topics discussed in this issue, that attest to the validity of that principle.

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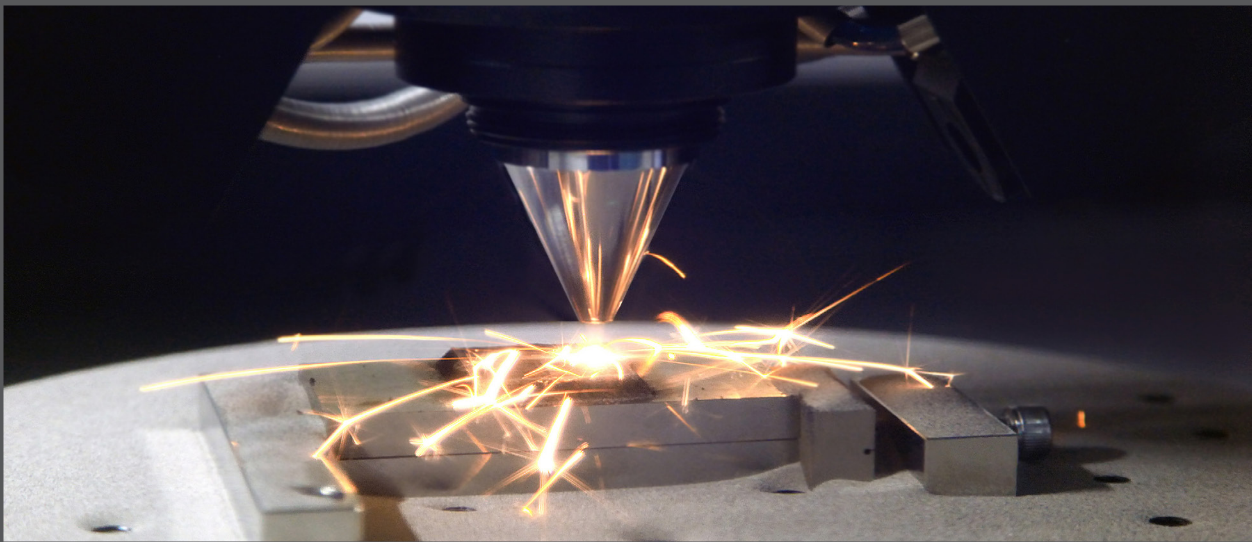
EDITORIAL

DOSSIER

The importance of lasers in Additve Manufacturing machines

Acknowledged as one of the most effective energy sources, lasers play a crucial role in different fields and Additive Manufacturing is no exception to that. If for many users, lasers are directly associated with more speed, the key to achieving product quality and increased productivity in manufacturing often comes down to the type of lasers the 3D printer is equipped with. Interestingly, different AM processes require different types of lasers. The article below aims to shed light on important laser parameters relevant to AM and highlights specific considerations for selecting the ideal lasers for one's AM equipment.



As you may guess, a laser beam can deliver a large amount of energy into a micro-scale focal area, allowing for a high degree of precision and speed for a wide range of materials.

Before diving into the most-widely used lasers in AM equipment, it's important to remember that a laser is usually made up of **a gain medium, a pumping energy source,** and **an optical resonator**. The gain medium within the optical resonator amplifies the light beam through stimulated emission, utilizing the external energy provided by a pumping source. The gain medium in use is therefore very important as it also permits to easily categorize lasers: **gas, solid state**, and **fiber lasers**.

That being said, **CO2 laser, Nd:YAG laser, Yb-fiber laser**, and **excimer laser** are often mentioned as the main representative lasers across the AM industry due to their widespread use within specific AM processes and other precision manufacturing processes.

For those who are new to this space, please note that the CO2 laser is one of the first gas lasers that has been developed in the industry. In CO2 lasers, the gas-state gain medium fills the discharge tube and is electrically pumped by a DC or AC current to achieve population inversion for lasing.

Nd:YAG lasers (neodymium-doped yttrium aluminum garnet laser; Nd3+:Y3Al5O12 laser) are a type of solid-state laser using rod-shaped Nd:YAG crystals as a solid gain medium.

A fiber laser is a type of laser where the active gain medium is an optical fiber doped with rare-earth elements whereas excimer lasers use 'excimers' as the gain medium and are pumped by pulsed electrical discharge to produce nanosecond pulses in ultraviolet (UV) region.

"CO2 lasers used to be used in both metal and polymer, but they really didn't have enough power to properly melt and fuse metal, so the metal AM industry moved to fiber lasers as requirements for higher powers and quality parts increased. Lasers also come in different power levels, and they can be turned up or down according to the parameter settings chosen for any given material or print feature desired. However, the design in power cannot be exceeded. For instance, a 500W laser will operate only up to 500W," **Alex Kingsbury**, Market Development Manager – Additive Manufacturing at **nLIGHT** points out.

Credit: Novanta. ti Series lasers. Average power ranges from 60 – 100W. Very commonly used CO2 lasers in 3D printing.

So far, we note that 3D printers based on **Stereolithography (SLA), selective laser sintering (SLS), Directed Energy Deposition,** and **selective laser melting (SLM)** can all be equipped with specific lasers.

Michael Rath, Inside sales representative at Novanta explains the differences in the use of lasers within these processes :

"The lasers used in Laser Additive Manufacturing (LAM) machines are primarily defined by the laser-material interaction of the base printing material. The central wavelength of the laser must align with the absorption spectrum of the 3D printing material. UV lasers (around 355 nm) are required for machines that use photo-polymer resins, CO_2 lasers (around 10 μm) are required for SLS machines that use polymer powders, and IR lasers (around 1 μm) are required SLM machines that use metal powders.

Photo-polymer resin machines typically use frequency-tripled UV solid-state lasers with 500 mW to 1.5 W output power. The polymer powder bed machines typically use RF-excited, enclosed, metal tube CO_2 lasers that are optimized for CW emission with 30 W to 150 W output power. The metal powder bed machines use single-mode and ring mode YB-fiber lasers with 200 W to 3000 W output power."

What are therefore the essential criteria for choosing lasers?

*"The **central wavelength** of the laser is the most [important] criteria for selecting a laser. As described above, the central wavelength of the laser must align with the absorption spectrum of the 3D printing material. In addition to wavelength optimization, lasers are qualified based on several performance characteristics including **power stability, divergence stability, wavelength stability, output power, and beam quality** (M^2). The **pulse-to-pulse stability** for pulsed lasers or **average power stability** for CW lasers directly affects the width of the printed material, and thus the quality of the part to be built. Divergence stability and wavelength stability can have a similar impact. The output power of the laser typically dictates the print speed and throughput. **Wavelength, beam quality (typically expressed as M^2)**, and choice of scan head will affect the size of the beam focus, and therefore define the minimal feature size of the printed part,"* Rath states from the outset.

nLIGHT's programmable high-power fibre laser can switch between a single-mode beam and other beam profiles without the use of free space optics (Courtesy nLIGHT, Inc.)

Based on these criteria, one can identify these specifications for the lasers often integrated into AM machines:

Laser	CO2 laser	Nd:YAG laser	Yb-fiber laser	Excimer laser
Application	SLA, SLM, SLS, LENS	SLM, SLS, LENS	SLM, SLS, LENS	SLA
Operation wavelength	9.4 & 10.6 μm	1.06 μm	1.07 μm	193, 248, and 308 nm
Output power (CW)	Up to 20 kW	Up to 16 kW	Up to 10 kW	Average power 300 W
Pump source	Electrical discharge	Flashlamp or laser diode	Laser diode	Excimer recombination via electrical discharge
Operation mode	CW & Pulse	CW & Pulse	CW & Pulse	Pulse
Pulse duration	Hundreds ns-tens μs	Few ns – tens ms	Tens ns – tens ms	Tens ns
Beam quality factor (mm·mrad)	3 - 5	0.4 - 20	0.3 - 4	160 x 20 (Vertical x Horizontal)

*Please note that these specifications may slightly vary from one provider to another. Source: Lasers in AM: A review.

If all of these specifications seem a lot to you, we recommend keeping in mind **Kingsbury's** advice to assess a good laser:

"For starters, there are some simple quality parameters you can check to quickly gauge the quality of a laser. The first is the beam parameter product (BPP). The BPP gives you information on how well a beam can be focused to a small spot size. This is relevant for AM as the laser spot size will determine your melt pool width.

Another good measure of beam quality for Gaussian-shaped beams, i.e. most laser beams used in additive manufacturing, is the M2 value. The lower the number and the closer to 1, the better the quality of the beam, and the more tightly you can control it.

An OEM that builds 3D printers will also consider other factors relating to the laser such as how much 'overhead', i.e. spare power, the laser has built in.

As we move increasingly to multi-laser systems, we also need to consider how well synchronized those lasers are."

The impact of lasers on 3D printer cost

While the focus has been made on 3D printers in this article, it should be noted that in AM, it's possible to use CO2 lasers to polish the surfaces of 3D printed polymer parts and make them smoother. According to Novanta's team of experts, this is a common procedure when printing customized shoe insoles.

On another note, it's no secret that one of the limitations that slow down the purchase of industrial 3D printers (metal 3D printers especially) is the expensive cost one must invest in these machines. To reduce these costs, several OEMs on the market (such as ONE Click Metal) that pride themselves on delivering affordable metal 3D printers, focus the development of their machine on one of the most expensive parts: **lasers**.

It's therefore important to keep in mind that even the price of these lasers vary from one category to another.

According to Novanta's team of experts, "The type of laser (i.e. CO2 versus fiber) and output power will impact the total cost of the printer. For example, for fiber lasers, there are roughly three categories:

1. Low-cost air-cooled continuous wave single mode fiber lasers up to 500 Watts

2. Mid-cost water-cooled continuous wave single mode fiber laser above 500 Watts

3. High-cost water-cooled continuous wave ring mode lasers

For CO2 lasers, there are similar categories:

1. Low-cost glass tube CO2 lasers with under 100W output power

2. Mid-cost RF-sealed CO2 lasers with under 100 W output power

Firefly 3D scan head: Compact solution designed to boost performance in the product line thanks to multiheaded machine capability that can achieve up to 100% overlap. Credit: Novanta

3. High-cost RF-sealed CO2 lasers with more than 100W output power"

To that, nLIGHT's expert notes that "lasers, or the 'light engine', i.e. the whole optical train including the scanner, form the very heart of a 3D printer, and typically the light engine consists of a reasonable portion of the total bill of materials for a 3D printer. CO2 lasers, as mentioned above, are cheaper than fiber lasers, so in cases where they work well, i.e. for polymer systems, they are the laser of choice." However, there is always the scanner choice as an option.

Additive Manufacturing techniques involving lasers are used in several industries, including electronics, medical, automotive, and aerospace. With the growing need for industrial applications, lasers will continue to play a crucial role in the pursuit of target performances. Their choice should therefore always take into account their operating principles, optical configurations, and comparative analysis of their respective advantages and limitations.

Editor's notes

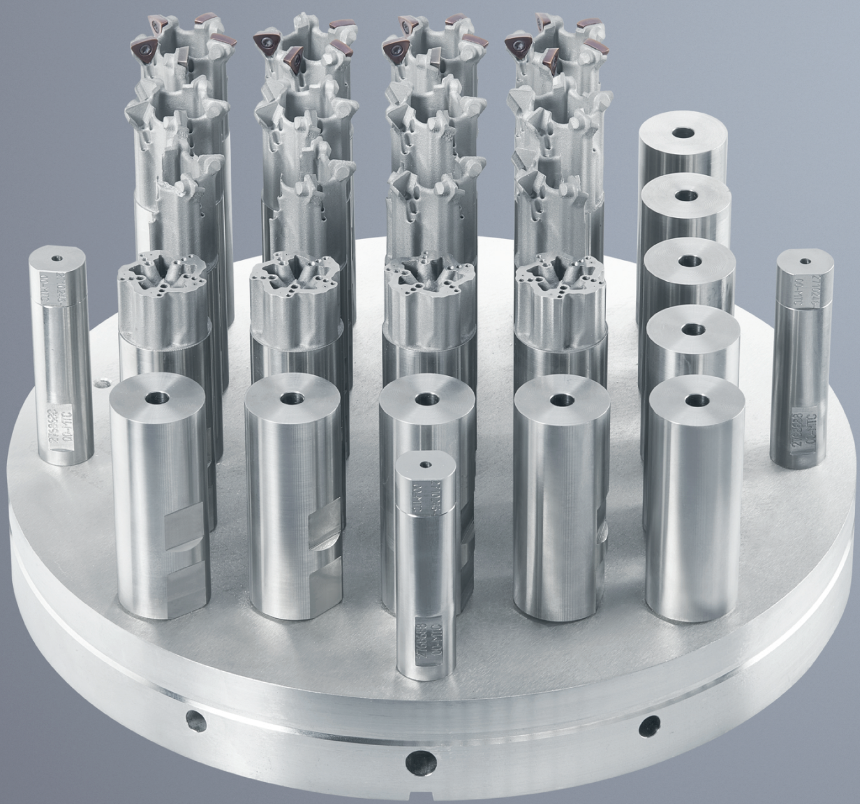
To discuss this topic, we invited two companies with key expertise on laser technologies.

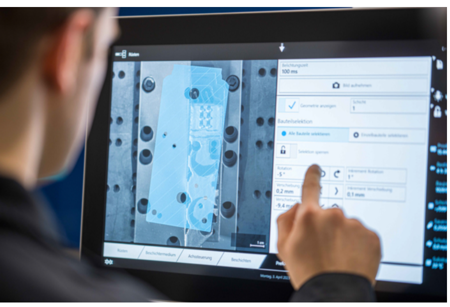
nLIGHT is a company founded in 2000 that develops, designs and produces laser technologies and products. The company provides the AM industry with high power industrial fiber lasers for L-PBF systems. They have 'standard' Guassian-shaped lasers starting at 500W and up to 1kW, and 'shaped' lasers, the AFX, that start at 1kW and currently go up to 1.5 kW. Lasers can be shaped through free-space optics, but the AFX is shaped in the fiber, which is unique to nLIGHT. In-fiber beam shaping allows for precise control of the beam, and therefore the melt pool. The AFX has six different ring beam shapes that can be selected, and each may be more suitable than the other depending on the material, geometry, and desired microstructure. According to the company's Market Development Manager – AM, with an increased understanding of the power bed, the metal AM industry has been able to successfully move towards ever higher powers in lasers. The current standard is 1kW. However, beyond 1 kW, the melt pool becomes unstable leading to excess porosity and poor quality parts. Ring-shaped lasers are the only shape of laser that enables higher powers to be applied to the powder bed while keeping a stable melt pool. Additionally, melt pool widths can be up to 300 microns wide; unleashing new levels of productivity in metal AM machines.

Through its **Synrad brand**, **Novanta** offers high-performance CO2 lasers from 10 W to over 200 W for polymer SLS 3D printing machines. Novanta also offers OEMs and system architects a broad range of high precision laser beam delivery systems and beam steering components for SLA, SLS and SLM applications. FIREFLY3D is Novanta's next generation 3-axis scan head designed for Laser Powder Based Fusion (LPBF) machines in additive manufacturing applications. The FIREFLY3D is an enclosed, compact solution designed to boost performance in the product line thanks to multiheaded machine capability that can achieve up to 100% overlap. Incorporated within the design are features to simplify installation and operation including automated scan field calibration and advanced features such as precise monitoring of the additive manufacturing process.

TRUMPF

Hybrid production thanks to preform technology





Maximize efficiency and save on material costs by printing directly on preform blanks, with precise geometry placement using our HMI and perfect alignment ensured by our advanced powder bed camera. Choose from sustainable reprocessing or high-volume series production to achieve high-quality results every time.

SOFTWARE: THE IMPERATIVE OF CYBERSECURITY IN ADDITIVE MANUFACTURING

Due to its strong reliance on digital data files and connectivity, AM by nature is subject to significant security exposures, from product malfunctions to intellectual property theft and brand risk, along with other new threats users of conventional manufacturing processes do not usually face. If acknowledging this reality is a business imperative, there is still a gap between assessing the potential impact of AM-specific cybersecurity concerns and what can be done about that.

Last year, analysts at Gartner forecast that 43 billion IoT-connected devices will be leveraged across the world. In the manufacturing industry alone and according to independent research analyst Jannik Lindner, 47% of manufacturers have experienced cyber-attacks on their Industrial Internet of Things (IIoT) devices. Speaking of the AM industry especially, Lindner continues: about "54% of manufacturers across the world do not monitor their systems for suspicious behavior." Yet, "60% of manufacturers reported suffering a disruptive cyberattack within the past 24 months."

I strongly believe that if these AM industry statistics are alarming, that's probably because companies deploying AM technologies consider addressing this issue an overwhelming task.

Different scenarios where AM-specific cybersecurity concerns may arise

One of the most mentioned AM-specific cybersecurity concerns is the case of design files that can be stolen. Other AM-specific cybersecurity concerns include the fact that design files can be changed to create flaws in parts, the toolpath can be modified to deposit materials incorrectly, dangerous or illegal parts or objects can be printed, digital twin or digital thread can be hacked, thus compromising maintenance or quality control.

Mark Yampolskiy, an Associate Professor of Computer Science and Software Engineering at Auburn University, summarizes these threats into three main categories.

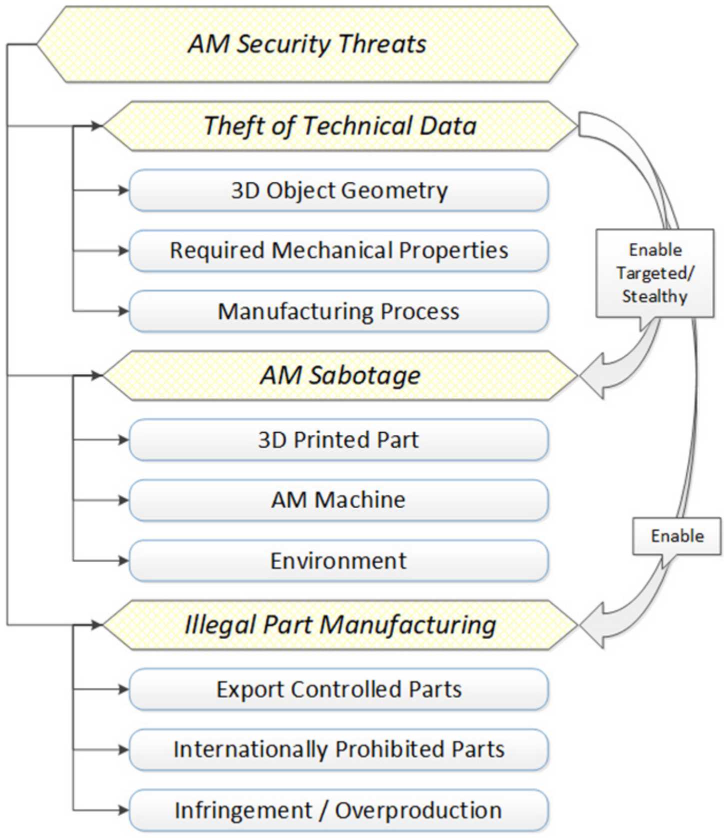
*"The first one is **Technical Data Theft (TDT)**, which is commonly discussed in the context of Intellectual Property (IP) protection. However, not all data whose loss the defender would like to prevent is or can be protected as IP. Furthermore, there are kinds of data that a defender might consider negligible, but that can advance the attacker's goals.*

*The second one is **Sabotage**, which is sometimes discussed in the context of integrity violation. However, not all integrity violations will lead to sabotage, and there are means to achieve sabotage without violating the classical integrity of cyber items, such as digital designs. In AM, sabotage can be directed immediately against the manufactured part or the machine. However, indirectly and more importantly, it can affect the system in which such part is integrated, or the environment of the AM machine.*

*The third is the **use of AM for Illegal or Unauthorised Part Manufacturing** (IPM). This is a threat distinct from the first two, because AM machines do not prevent manufacturing anything that is physically possible. Therefore, it is rather a legal concern for which a technical solution is sought.*

Lastly, as AM Security is still a young discipline, it is likely that new threats will emerge. For example, we recently discovered that it is possible to embed additional information in the STL design file without *affecting the design or printed part (using something known as 'steganographic channels'). This threat does not aim at AM, but rather uses AM as an 'accessory' to further other attacks.*

There are also 'symbiotic relationships' between threats. For example, TDT can be a precursor for a targeted sabotage attack (e.g., to design a defect for a specific part that will degrade its functional characteristics to a certain degree) or for IPM (e.g., to infringe parts using a stolen design). The steganographic channels in STL (and probably in other digital file formats used in AM) can be used to exfiltrate the stolen data 'piggybacking' on innocuous-looking design files sent outside a company or an organization."



Credit: **Mark Yampolskiy**

Potential impacts that may arise therefore include financial fraud, reputation damage or theft of IP, business disruption, destruction of critical infrastructure, threats to safety or even regulatory infringement.

So, how do you map these cybersecurity risks across the AM lifecycle?

As seen above, cybersecurity threats can occur at different levels. Therefore, it's crucial to understand how data are transmitted and processed – and how information is communicated throughout the AM process, from design, build, and quality assurance monitoring, to testing, delivery, and distribution. Understanding that process comes down to establishing the digital thread specific to your organization and most importantly, identifying the stakeholder that could be impacted the most.

That stakeholder could be the AM equipment manufacturer, the 3D part designer, the material supplier, or the end customer.

Defining which stakeholder is impacted the most by a security threat in an AM workflow "*depends on the threat we are talking about*", **Yampolskiy** outlines before adding: "*original equipment manufacturers (OEM) and 3D part designers are probably the most affected by TDT. Their concerns might be different, though. The OEM is likely to be mostly concerned with their 'secret sauce', such as scanning strategy and process parameters for a specific material. The 3D part designers are likely to be more concerned about their design being stolen and infringed upon.*

End customers are more affected if we talk about sabotage of parts. Having said that, an attack on the material supplier can be used to sabotage the feedstock to sabotage parts manufactured with it – a physical equivalent of what is known in cybersecurity as a 'supply chain attack'."

What steps can be taken to address AM cybersecurity threats?

First and foremost, it's crucial to keep in mind that **cybersecurity is not just an IT department issue.** Therefore, everyone in the organization should be aware of the risks and ensure basic precautions are followed to prioritize safety.

If there is a scenario where we can't address all the security challenges at the same time, defining the most important hurdle to address can be "*a tough choice because different stakeholders might be more or less exposed to different threats. And this might change over time. Just two years ago I would answer the question by pointing at TDT. However, considering the current global instability and the return of great powers competition, I would say that Sabotage should be our main concern, at least for the time being*", the associate professor points out.

That being said, it's never a bad idea to first **conduct a thorough risk assessment** to pinpoint the risks most pertinent to one's specific AM scenario. This could also help pinpoint potential additional threats that might come into play with regard to AM applications.

One could also assess **if lessons from well-known cyber-attacks could be applied to AM**. According to a report from Deloitte on "3D opportunity and cyber risk management", the "*strategy, "test once, satisfy many," can enable organizations to consider the applicable regulations in the same vein to avoid duplicating efforts, particularly when used in concert with design approaches that incorporate security directly into the design of products. They can then create a comprehensive risk management framework to evaluate their regulatory environment to best address their specific cybersecurity footprint. Given the fact that AM processes include both digital and physical components, a combination of strategies focused on both IT systems and physical objects may provide the most comprehensive initial approach."*

Furthermore, since the manufacturing process chain starts with the design – and given the fact that it is often the first cybersecurity risk considered, a part of the basic precautions can be the **protection of one's design from the start.** Together with his partners for example – they include ***Dr. Moti Yung*** (Google LLC, Columbia University), ***Dr. Nikhil Gupta*** (New York University), and ***Hammond Pearce*** (University of New South Wales) –, Yampolskiy has been developing a "*solution for integrating robust* *digital watermark into STL design files."*

Another step could consist in **ensuring protection into one's print process**. Security solutions that could be implemented, depend on many factors including the type of AM technologies used, or even the standards one can afford to pay. For example, Velo3D printers can be configured to meet the rigorous security requirements of the United States Department of Defense (DoD). To do so, their users should achieve the **Security Technical Implementation Guides** (STIGs) compliance developed by the Defense Information Systems Agency (DISA). According to OEM Velo3D, *"in the realm of metal AM, the application of STIGs is particularly crucial due to the unique challenges and vulnerabilities inherent in this field. The technology involves complex processes that integrate digital designs, advanced materials, and precision engineering. Each of these components introduces specific security risks that STIGs are designed to mitigate. For instance, the digital design files used in metal AM are highly sensitive. If compromised, they could lead to significant intellectual property theft and national security threats. STIGs provide comprehensive guidelines to secure these digital assets, ensuring that they are stored, transmitted, and accessed in a manner that minimizes the risk of unauthorized access or tampering."*

Other practices are seen in tracking and tracing. They include the **use of RFID tags** to track AM-produced products throughout the supply chain.

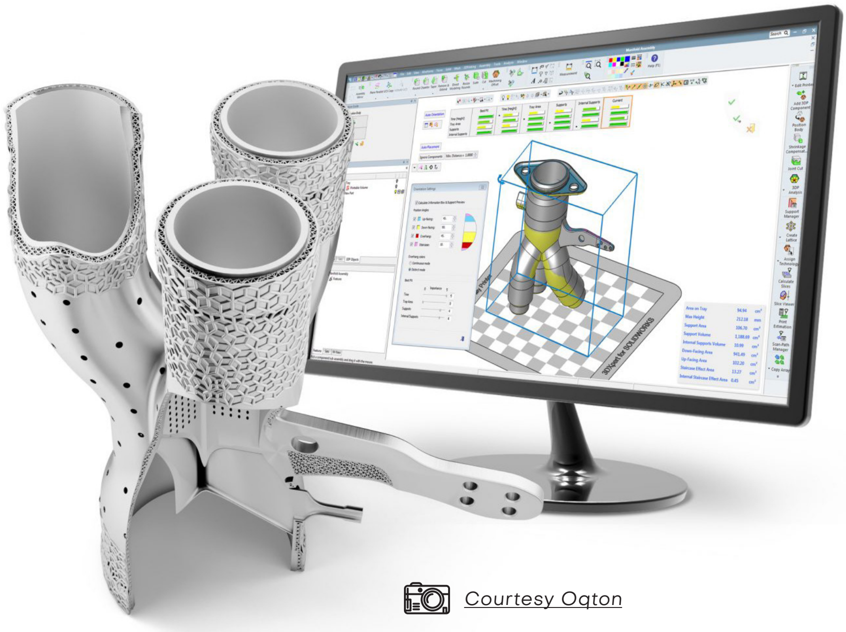
Speaking of a non-invasive solution that could be used to detect sabotage attacks, Yampolskiy explains they *"use what is known as 'side channels', focusing on the power side channels of individual actuators. The approach has several advantages compared to pure cybersecurity solutions. To name just one, such an approach allows to air-gap the monitoring system from the monitored 3D printer, thus significantly increasing the difficulty of their simultaneous compromise. The project for the adoption of this approach to PBF is funded by NIST."*

Concluding thoughts?

Improved cyber protection will give manufacturers and their customers the confidence to try new business practices and models they can't consider now. The potential for new opportunities supported by cybersecurity will draw in innovative companies with cybersecurity expertise to provide solutions for Additive Manufacturing users and AM technologies providers. While we look forward to sharing cybersecurity solutions applied across business models such as remote manufacturing, and/or on-demand spare parts production, one should keep in mind that cybersecurity threats ultimately drive change and growth – especially when tackled creatively.

SOFTWARE: INSIGHTS INTO KEY 3D PRINTING FILE FORMATS

I have always compared a 3D printing file format to a language that a 3D printer can understand. Just like there are languages different populations can speak, there are 3D printing file formats some 3D printers can process even if they are powered by different technologies, and there are file formats that are proprietary to some 3D printers. How does one make the difference between the file formats and what are the pros and cons that one should know? The article below provides insights into key 3D printing file formats and how they are used.



Courtesy Oqton

It may seem trivial to discuss such a topic at this level of maturity of AM. Yet, we shouldn't forget that going back to basics is not only for beginners in AM, it's also for advanced users to realize the advancements made in the first stages of the 3D printing process.

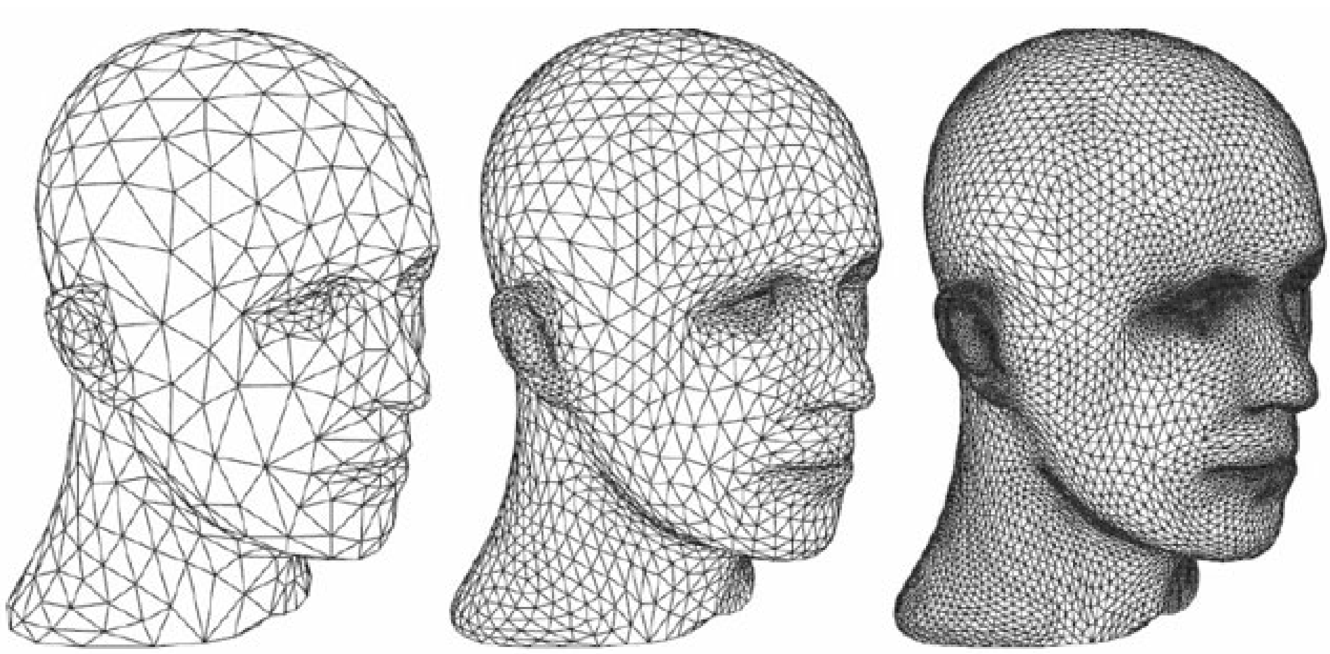
To beginners of AM, the preparation phase before 3D printing requires undertaking the 3D modeling and slicing steps. 3D modeling consists in using software to create a mathematical representation of a 3D model. Slicing consists in converting a 3D model into a series of horizontal layers and generating the necessary instructions for a 3D printer.

That being said, no matter what the 3D printing file format is, the function remains the same: **turning raw materials into solid parts.**

So far, we have identified about **10 different types of 3D printing file formats**: STL, OBJ, AMF, 3MF, Gcode, X3G, VRML/X3D, FBX, PLY, STEP and IGES. Of all these formats, the most widely known ones include STL, OBJ, AMF, and 3MF.

A few words on the main 3D printing file formats

STL (which stands for ***Standard Tessellation Language***) is probably the first format any 3D printing user will hear about. It breaks down a 3D object into triangles or facets, creating a mesh of the part to 3D print. The mesh represents the surface of the part; it allows that file to be printed layer-by-layer until the solid object. STL files simply contain the surface geometry of a virtual 3D object, with no other properties. This file format is universally supported by 3D CAD software.



STL files store 3D models as a mesh of triangles (Source: Wikimedia Commons)

OBJ derives from Wavefront Technologies's Advanced Visualizer software. While most software will export to OBJ, its use is acknowledged in color 3D printers. Normally all slicers accept OBJ files as input. The 3D data entails high-quality geometry, texture information, and full color.

AMF (stands for Additive Manufacturing File). This recently created format can provide more information and higher accuracy than just the mesh surface representation. Developed with an eye towards addressing some of STL's limitations, AMF brings color, materials, and even multiple textures into the mix – not to mention that it handles well geometry.

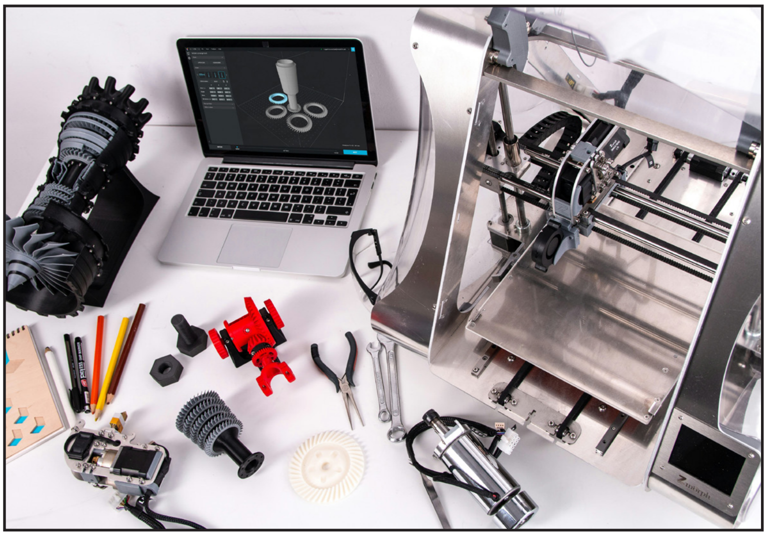
If AMF is often seen as STL's successor, 3MF (which stands for "**3D Manufacture Language**") can be seen as the kid of superhero parents. As a matter of fact, it benefited (and still benefits) from a lot of media hype due to tech giants (Microsoft, Autodesk, HP, Viaccess-Orca, etc.) who decided to join forces to create and enhance it. It can integrate the model's geometry, as well as details such as color, texture, and even printing directions, all in a single file.

Pros and cons to take into account

3D printing file formats	Pros	Cons
.STL	Easy to create	Does not include information about color, texture, or material properties May not deliver the accuracy required for curved or organic shapes.
.OBJ	Better for curved/organic shapes	Can be difficult to work with when creating very detailed parts Similar to .STL in that it contains 3D geometry information only (vertex normals, geometric vertices, polygonal faces and texture coordinates.)
AMF	Provides a lot of information Better for complex applications	May not be compatible with all 3D printers yet Slow adoption (lack of marketing strategy to position itself as the necessary successor of .STL
3MF	Provides a lot of information, well known and open source Able to use a compressed ZIP format	Raises concerns about how much of an open-source format it is going to be in the future

Other 3D printing file formats

While this article focuses on the most widely known file formats, one should keep in mind that one can print from basically any 3D file – even though they are not initially designed for 3D printing.



G-code, short for "geometric code," serves as the final output of the slicing software which converts CAD and VR objects into movement instructions that a 3D printer can interpret.

FBX: this proprietary file format owned by Autodesk is ideal for interoperability between Autodesk software programs. Just like VRML and its successor X3D, its intended use is for rendering effects.

PLY (Polygon File Format): Designed to store geometrical data generated by 3D scans. Besides its geometrical elements, it can encapsulate elements such as color, texture maps and transparency. For 3D printing, one can convert a PLY file into the format accepted by the 3D printer.

STEP and IGES remain the CAD standards for engineering applications. Rather than polygons, these file formats use complex NURBS representations for precision. Their use in 3D printing is often subject to debate as 3D printers often require simpler data.

Key considerations to select a 3D printing file format

3D printing file formats can be divided into two categories: 3D modeling files that contain all design information and sliced files that contain instructions for the 3D printer based on the 3D model files.

It may seem redundant in the AM world but the choice of a file format depends on several things including the purpose the user is looking to achieve. Answering a couple of questions might help.

What are the project requirements? Does the part require high details, textures and color – then you might want to go for OBJ or 3MF formats for instance.

What/how is the 3D printer compatibility? Some 3D printers have proprietary file formats (like MakerBot and its .X3G file format); others just work best with some formats so just ask the OEM before purchasing the machine.

Is the file format influenced by some software tools? Ensuring your file format, printer, and software work seamlessly together is critical. Think of it as a finely tuned orchestra; if one instrument is off-key, the whole symphony is affected. It all comes down to what enhances the project the best.

Comments from founding companies on the AMF & 3MF file formats

Given the constant comparison between AMF & 3MF, we asked two companies contributing to the development of the AMF & 3MF formats to share their thoughts on how each of this format should be used.

Q&A with Bob Zollo, President, Avante Technology, LLC

Software companies Avante Technology and Mind in a Box recently developed a free source code for an AMF file converter. Called **AMFSample**, and now available to the public, this software enables the conversion of STL files into the ISO-compliant AMF format.

1. What are the key factors influencing the choice of a file format for 3D printing?

The factors may be different depending on the intended application and industry. For example, STL or OBJ formats may be adequate for simple, lower precision prototypes. These formats are usable royalty free and are supported by the great majority of software applications and 3D printing systems. Engineers and hobbyists alike are familiar with STL, so there are no economic or IP licensing barriers to use. Functionality and precision may be limited, but adoption is easy with minimal investment.

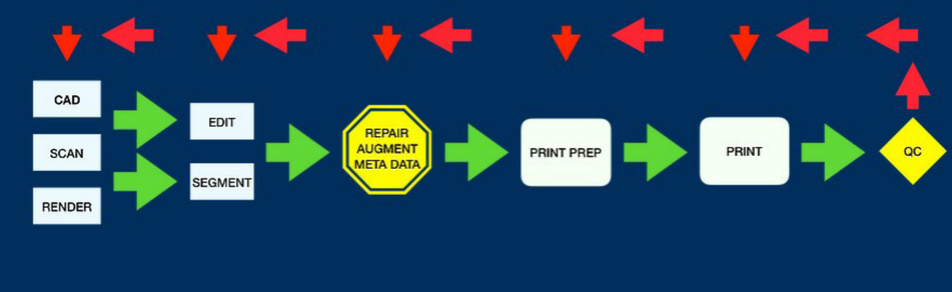
Any manufacturer seeking to adopt and leverage true additive manufacturing(«AM») to make quality parts and assemblies for commercial, medical or military use will consider a broader range of factors, including: legal, regulatory, cost of adoption, cost of migrating from historical formats(if any), maintainability, compatibility with software applications and systems used in the manufacturer's workflow, the expected life of the format's usefulness for the intended application, and adaptability for planned and future use.

In some industries, namely the medical, aerospace and defense ones, there are regulatory requirements that factor in on the decision. The FDA and EU medical authorities have recently published requirements for the manufacturing of medical devices, that require validation of accuracy, precision and overall quality, as well as verification of these attributes by authorized third-party auditors.

The ability to include all design and workflow-related meta data needed to verify the printed device meets the intended accuracy, precision, and quality within the file, provides a reliable method to programmatically validate and verify quality. Such an integrated approach can significantly reduce the potential legal liability for AM medical device manufacturers, while reducing quality assurance costs. Defense agencies and aerospace regulators have similar requirements, as well as policies for including or linking legacy format documentation to the 3D file. ISO/ASTM 52818 provides more detailed technical guidance on this topic.

Finally, some government agencies and commercial companies have policies favoring products produced using international standards-based technology. ISO and ASTM are the two key global standards organizations publishing AM-specific standards, such as ISO/ASTM 52915, which defines the specification for the AMF format («additive manufacturing format»).

Source: Avante Technology



Add Design & Process Meta-Data Within AMF Format Files to Optimize Your Print Quality

2. According to you, does STL remain one of the most widely used formats because it is widely known?

From my perspective, STL continues to be widely used because of its ease of adoption, minimal cost, perception of low legal risk and broad support by conventional software and printing systems. There is also a great deal of inertia in the industry, and frankly, lack of understanding of the benefits of adopting more advanced formats.

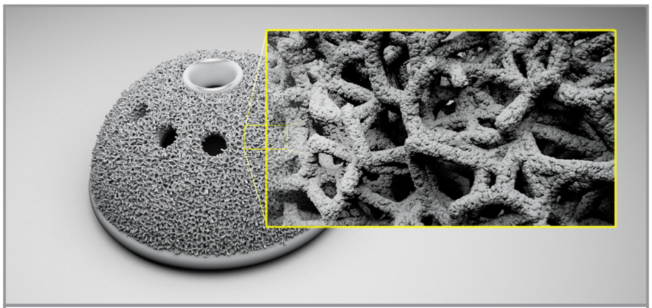
There is a general perception that the risk and cost of upgrading to an advanced format like AMF or 3MF may not be justified. There is a need for industry education on the technical, legal, quality and efficiency benefits these formats provide. While I believe STL will continue to be used broadly for many years, a growing number of manufacturers will be compelled to take the leap to AMF or 3MF as regulatory requirements increase the economic and risk management advantages of upgrading. In the long run, higher quality and workflow efficiency resulting from the use of advanced formats will motivate more manufacturers to migrate to one or both of these formats.

3. What are the key advantages and limitations of AMF and 3MF?

Both formats are robust, advanced formats based on XML that contain a myriad of useful features that STL lacks. They are both extensible. Version 1.0 of the ISO/ASTM standard for AMF was initially published in 2014 and has been updated twice. It was the original international standard additive manufacturing format. A few years later the 3MF Consortium was formed to publish and maintain the specification developed by Microsoft. There is significant overlap in the structure and capability of these formats. A few significant differences are as follows:

a. AMF is an international standard jointly published by ISO and ASTM and approved by virtually all member countries. 3MF is a specification published by the 3MF Consortium and controlled by a small number of major companies. ISO standard specifications provide manufacturers an advantage in some government regulated industries, such as medical, defense and aerospace.

b. The 3MF consortium has done an effective job actively promoting its format and educating leading AM systems companies and manufacturers. ISO and ASTM are restricted by their policies from doing much evangelization. They rely on individual companies to fund and implement market education and support, so awareness of the AMF standard and benefits is not as well known.



The 3MF Beam Lattice Extension enables for lattice-type geometric information to be used during additive manufacturing at all scales. Image courtesy of Autodesk.

c. Verson1.2 of the AMF specification includes a broader range of defined meta data tags, as well as optional custom meta data tags that provide a powerful means of incorporating quality, IP, confidential and legacy documentation information within the file. 3MF has a narrower range of defined meta data tags, but the specification includes useful features like 2D thumbnails and digital signatures to validate the file authenticity.

d. Both 3MF and AMF specify use of 3D meshes to define the surfaces of the objects. AMF allows for alternative methods to define the objects, such as constructive solid geometry.

e. Both formats include support for assemblies, but the AMF support is broader. Its «constellations» support provides for any number of discreet objects oriented at specified relationships and orientation with each other.

f. Both formats support the sRGB color model at triangle level up to objects, but AMF allows for optional color models. It also provides for color gradients at triangle level up to objects.

g. Both formats support specification of materials by object, but AMF provides for specifying composite materials and gradient blending of materials by object or component volume.

h. 3MF defines a «package» that includes thumbnails, core properties, digital signatures, custom part, the 3D model with associated object thumbnails(if any), 3D textures(if any) and print tickets. AMF provides for inclusion of additional files integrated with the mesh file in a zip file. AMF includes the «.url» meta data tag that enables users to list a specific web address where additional proprietary or confidential information can be accessed via user-initiated authentication. This can be of unique value in protecting copyrights, and sensitive information, such as military technical data packages with confidential contents.

i. ISO and ASTM provide for a member peer review and democratic voting process on approving new revisions to the standard. With global membership of hundreds of organizations, including academic, research, government agencies and commercial companies, a draft revision is reviewed and critiqued by a large and diverse number of professionals and stakeholders before being approved for publication. My understanding is that the 3MF consortium provides for any member to provide input and critique to draft revisions, but only full dues paying «Steering Member» companies (18 commercial companies) vote.

j. The 3MF consortium has published a few optional add-ons to the basic specification. They offer advanced support for lattices. AMF currently lacks any optional add-ons, but ISO TC261 joint committee for additive manufacturing has published a number of technical guidance documents, including ISO 52918 on medical AM applications. Several other ISO standards reference AMF as part of their AM specific specifications, and more industry specific guidance for the AM universe is being developed for future publication.

In summary, both formats have

some valuable, advanced features that enable manufacturers to design and build more sophisticated parts using additive manufacturing more efficiently. Both formats will be used by a growing number of manufacturers as the use of AM technology broadens to address a greater number of parts and assemblies around the world.

4. Any last words to add?

I encourage readers to learn more about both formats and assess the merits for their specific applications and industry.

On balance, we think the prudent choice for a great number of companies will be to consider the strategic value of employing ISO standard AM specifications, including AMF in their design, production, quality control and quality assurance programs. With 28 published standards on materials, process, design, quality testing, and related topics, and 31 new standards projects in development, most manufacturers will find they will benefit from utilizing these integrated standards to improve the quality and efficiency of their AM activities. With another 30 standards products under development, the ISO standards and technical guidance cover the entire *«design to print to post process to quality assurance»* workflow (see enclosed ISO/ASTM chart).

Currently, the ISO TC261 technical working group J64 on file formats is seeking input from industry stakeholders for creating industry and application specific technical guidance, including additional meta data fields for improved workflow efficiency. Interested parties can contact me directly at: bobz@avante-technology.com

Pérez Pelage, Head of Emerging Business – Industry at Viaccess-Orca, on the 3MF format:

Viaccess-Orca, a founding member of the 3MF consortium, has contributed to the specification of the security of this file format by providing a solution for protecting manufacturers' intellectual property, guaranteeing this way the integrity of 3D models and controlling the number of parts produced.

"To date, 3D printing is an emerging technology, which means that not everything in the production supply chain is standardized: Each 3D printing machine will have its own process, its own data format, its own materials and so on.

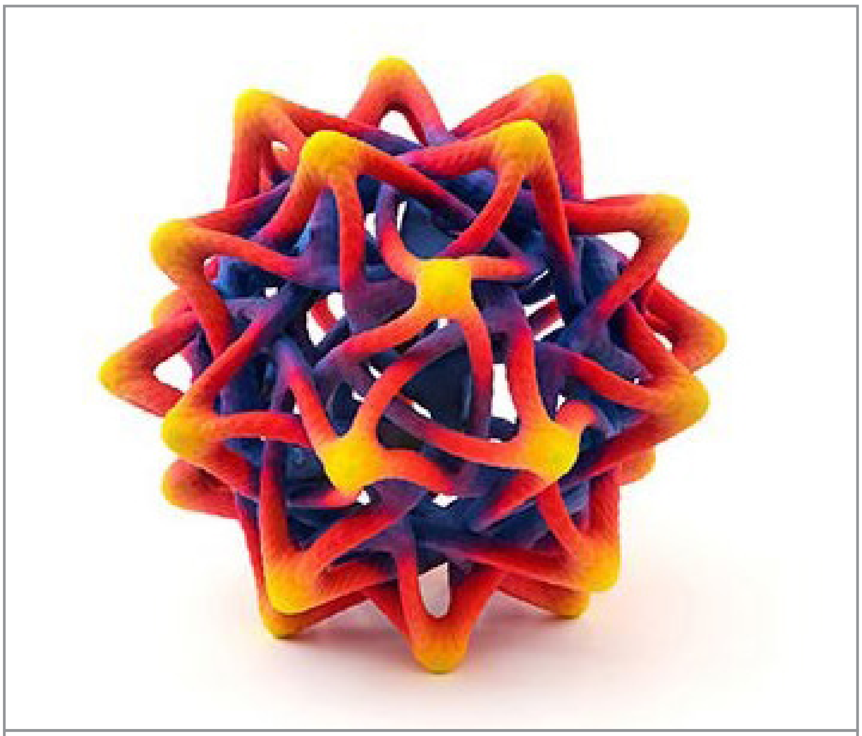
To reduce this fragmentation of the production supply chain, we need to adopt standards such as 3MF (3D Manufacturing Format) associated with the successor file format to STL.

The 3MF format fills the gaps and complexity of existing file formats, making the various processes reliable, reproducible, and scalable, from prototyping to production.

It includes information on materials, colors and other information that cannot be represented in the STL format, which has been widely used for over 30 years.

Unlike the AMF norm, which has not been widely adopted by manufacturers and whose specification is older, the new 3MF file format (alongside other solutions designed for protecting manufacturers' intellectual property), can guarantee the integrity of 3D models and control the number of parts produced, making it possible to deploy secure, on-demand distributed manufacturing.

To facilitate the scaling up of additive manufacturing with 3MF, the players in the production supply chain will have to certify the production ecosystem and, more specifically, the 3D printers."



3MF full colour part. (Image credit: 3D Systems)

Interested parties can find more information, including technical guidance, sample applications, open-source code and developer forums at the following web sites:

www.iso.org/committee/629086/x/catalogue/

www.committee.iso.org/home/tc261

www.AMFtools.org

Avante-technology.com

www.astm.org/committee-f42

www.3mf.io

www.viaccess-orca.com/

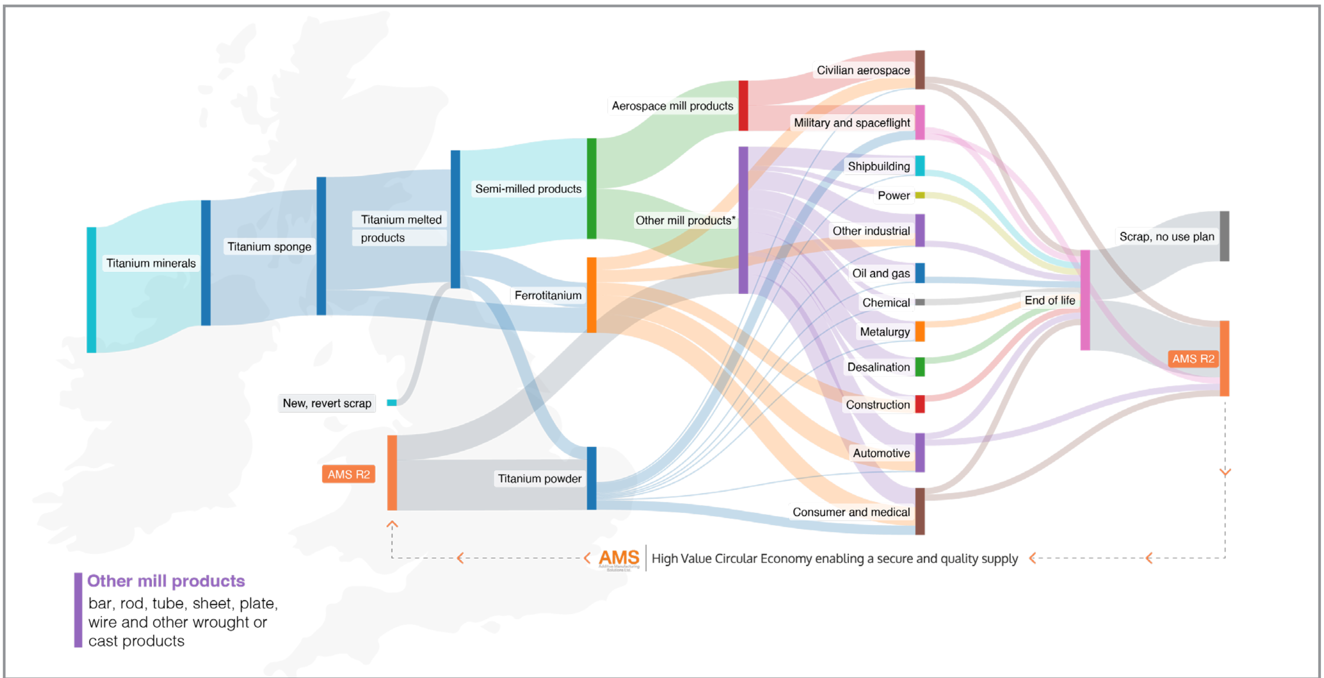
Expert column - Materials

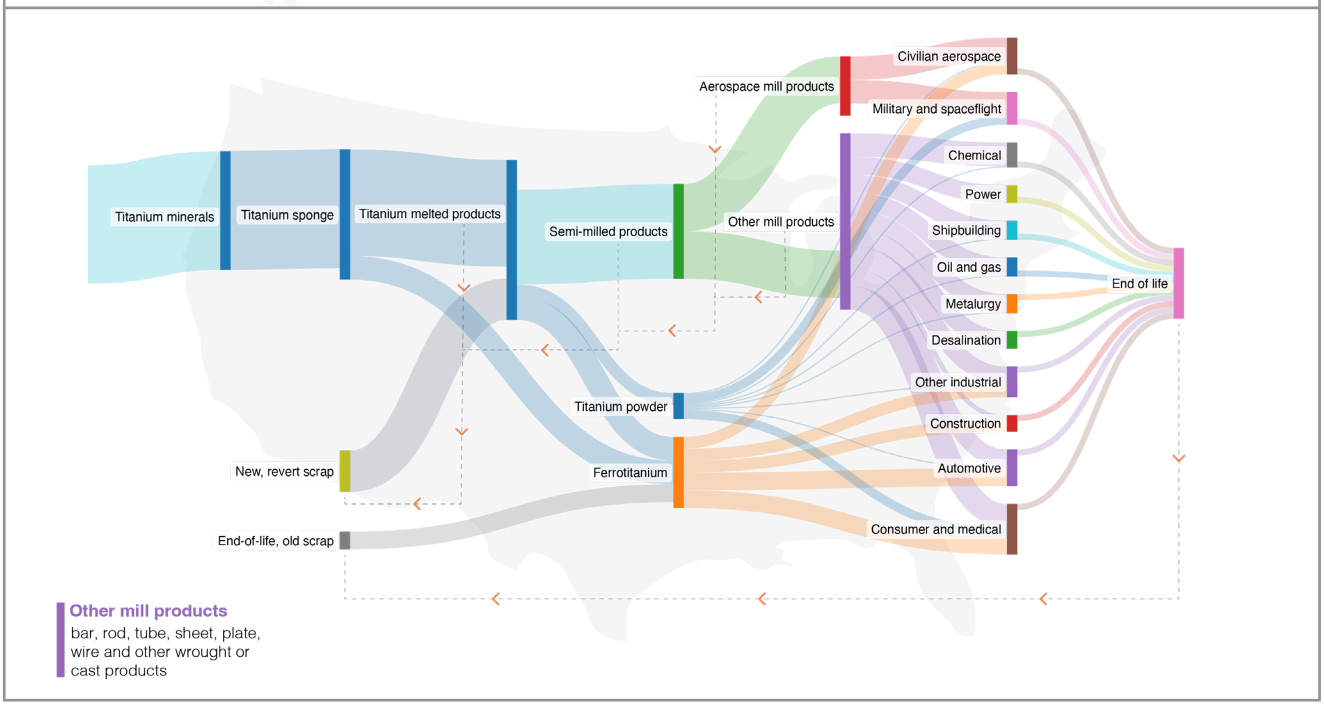
Additive Manufacturing Solutions Ltd. creates sustainable and secure titanium supply

Titanium and its alloys have been readily used in many industries to great effect however it is the aerospace sector which has seen the main benefits. Titanium has very high strength and low mass giving the coveted high strength-to-weight ratio alongside its chemical and corrosion resistance and ability to work in high-temperature environments. Titanium has been and continues to be an important alloy across civil and defence aviation.

In a post-Brexit world, Covid and amid conflict in the Ukraine, alongside increasing tensions in the South Pacific, there is a geopolitical situation in which the future needs for titanium within the aerospace sector are put at risk for supply. Russia and Ukraine have long since had key contributions to the titanium supply market and within the whole of the West of Europe there is not a single capability that can process titanium in its rawest form, sponge. In the US the Department of Defence has addressed similar concerns with significant funding for operations looking to produce this critical mineral in land. The Western world feels the same pinch.

The **graphics below** shows the standard flow of titanium from source to end of life:





The US have a much better utilization of titanium from end of life and scrap on shore already compared to the UK and Ireland. This is of course a great thing however it does not truly support high-value manufacturing need for security in supply and to minimize the impact that conflict can have on access and cost.

Focussing in on the UK and Ireland, we can see the relative quantities of titanium and the flow in which they take through processing and industrial vertical routes. Whether the end of life is short or long term there is not any significant recycling capability. That is until now.

Additive Manufacturing Solutions Ltd (AMS), based in Lancashire, UK has developed a solution to the titanium supply problems facing the supply of metal powders for Additive Manufacturing.

AMS is an expert in metal additive manufacturing with its training academy, the AMA, alongside its process excellence. The final addition to this is their material development capability. AMS has metal powder AM processes in house in which the energy source, electron beam or laser, melts the powder in these selectively defined areas.

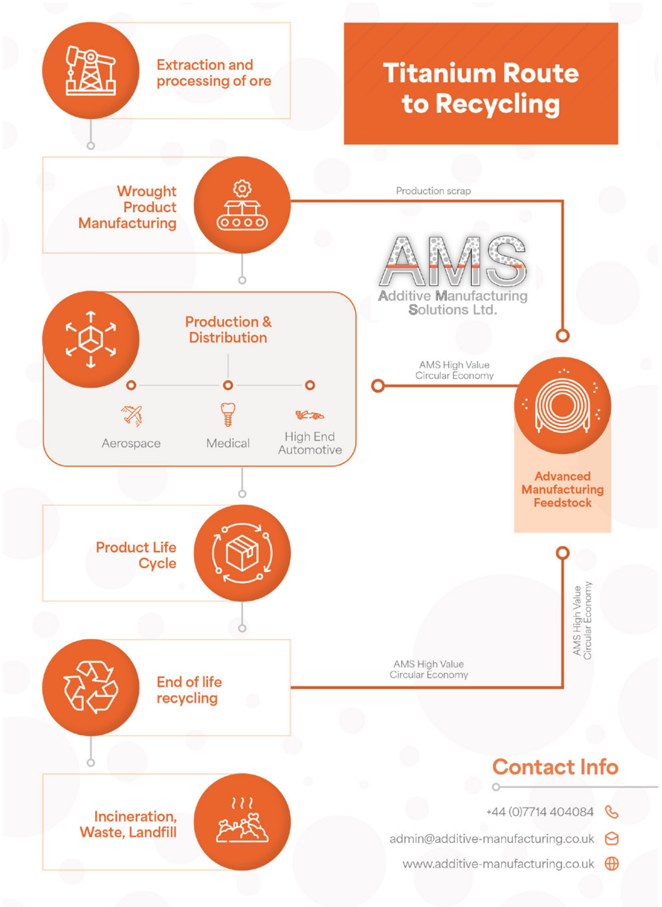
The titanium powder market globally is worth just a fraction of the global titanium market and the supply fluctuations induced by conflicts have a larger impact on the titanium powder market. Over recent months, the availability of titanium powder and prices have ranged from **$150-275/kg and lead times up to 5 months for supply** in some instances. With the Global Combat Aircraft Programme (GCAP), AUKUS alliance for submarine supply and a buoyant market in the UK and the US for space manufacturing the need for titanium and the opportunity for AM are large but the risk in supply is also high.

AMS has therefore developed a solution called **R^2**. AMS was awarded funding from **Innovate UK** to build technical feasibility into its theoretical approach to turning aircraft parts into powder. This project was successful, and the process was optimized. AMS' first major customer was the **Ministry of Defence** (MoD), due to the availability of titanium aircraft parts as a potential supply the MoD, wants and can play a key role in the future supply of AMS' high-value circular economy product, a **recycled titanium powder**. Used in 100% recycled or a recycled blend (like many food packaging), AMS can support the supply chain risk mitigation for the UK and its allies but perhaps more importantly is a key enabler in a more sustainable future.

AM is often touted as a sustainable manufacturing process due to its minimal waste capability. ***Though one could argue that the energy used to create powder versus the energy waste in the production of scrap from a machining process for example makes them very similar processes.***

The unique opportunity for remaking powders and creating a fully circular opportunity does provide a potential significant energy saving. The feedstock for the R2 process does not need to be mined, sponge created, cast, wrought and moved thousands of miles so the footprint left by the material reduces significantly. AMS estimates that the R2 process creates just 3% of the embedded carbon of a virgin-produced powder.

Supply chain security, minimizing the environmental



Legend: AMS' process to recycle titanium

impact, increased resilience, and the development of a UK feedstock supply, all developed in the UK. AMS has future developments underway for alternate critical metals, and other forms, like rod and wire underway, AMS' tag of innovative solutions for a sustainable future seems to be very fitting. AMS is also developing a deployable variation of this capability allowing at point of need capability.

With a critical mineral supply at its heart and unaffected by the geopolitically turbulent world we live, AMS believes its technology has a bright future. AMS' Founder and CEO, **Robert Higham** states, "*AMS was created to bring our process expertise for material development and AM to support the growth of our industry. To do this, the need for a controlled supply of feedstock became our mission. We now have proven what is possible for innovation and sustainable-minded companies. Please reach out to us if you want to work with us across material supply or AM. Let's change the world of advanced manufacturing together*".

Contact details: admin@additive-manufacturing.co.uk
www.additive-manufacturing.co.uk

INTERVIEW OF THE MONTH : THE DIFFERENT WAYS ADDITIVE MANUFACTURING CONNECTS TO (CNC) MACHINING

Credit: M&H CNC Technik GmbH

Have you ever realized that those who first built extensive experience in conventional manufacturing processes believe that success with AM should be achieved with some conventional manufacturing "element"? Considering (CNC) machining here, one should note that in theory, those professionals are not wrong. It just takes some solid experience to identify the different ways Additive Manufacturing and machining affect one another and how one can make the most out of them.

Whenever a comparison needs to be made between AM and a "traditional manufacturing process", there is a great chance that that traditional manufacturing process is machining, CNC machining specifically (CNC standing for Computerized Numerical Control).

In case you are new to the manufacturing world, please note that CNC machines are automated machines operated by computers executing pre-programmed sequences of controlled commands. Ideal for low to mid-volumes of parts, these machines can create parts with very good accuracy and precision by removing material, rather than adding it.

According to **Patrick Herzig**, CEO of M&H CNC Technik GmbH, CNC machining is *"particularly crucial in industries that require strict tolerances and consistent quality, such as aerospace, automotive and medical."*

CNC machining is a key tool in the production environment of the part manufacturer as the technology helps the team achieve complex geometries with high precision.

"The repeatability that CNC machines offer, allows us to scale efficiently and optimize production costs while maintaining product quality. When combined with modern 3D printing technologies, CNC comes into its own by allowing us to take advantage of both manufacturing processes to develop innovative and complex products faster and more


Patrick Herzig, CEO of M&H CNC Technik GmbH

cost-efficiently. For M&H, the use of CNC technologies is not only a matter of manufacturing efficiency but also a strategic advantage that allows us to respond flexibly to the rapidly changing demands of the market and offer customized solutions for our customers," the CEO adds.

A few areas where AM technologies and (CNC) machining enhance each other

First, machining.

Interestingly, AM users who rely on (CNC) machining can leverage the **strengths of this technology to produce metal 3D printed parts**. Let's take the example of **laser powder bed fusion (LPBF)**, one of the most-widely used metal AM processes.

In general, machining can be used in several ways to support this process: to separate the part from the build plate in an LPBF machine, one can use a wire EDM machine. It is also possible to resurface build plates for re-use via face milling of these plates on a vertical machining center or even to ensure the finishing part of the AM process with machining.

Furthermore, in some applications, design for AM is to a certain extent design for machining. Production metal parts can have intricate and complex forms – and to deliver their final tolerances, it's often pivotal to machine them. To do so, the engineer would therefore need to anticipate how the part will be held in the machine tool. In such cases, machining knowledge is important to design and

Credit: M&H CNC Technik GmbH

engineer the additive build effectively.

"The combination of both manufacturing technologies opens up new possibilities in production by combining the strengths of both processes. On the one hand, additive manufacturing enables the rapid creation of complex geometries that would be impossible or very costly to produce using traditional methods. On the other hand, CNC machining offers the necessary precision and surface quality to bring these parts to the specifications that our customers expect, even in post-processing. By combining these technologies, we can not only shorten development times, but also increase the functionality and quality of the end products", **Herzig** emphasizes.

As the focus of this article is on **CNC machining**, it should be noted that this technology could be crucial to support the LPBF work. As you may know, a build failure can happen at any time during the manufacturing process. To prevent it (and save cost), one can overspecify support structures and add stock around 3D printed features. This way, the additional stock protects the part's value without adding substantial cost or effort later in the process.

On another note, it's easier to achieve precision when the 3D printed part is small. With bigger parts, it's important to control material deposition. Although 3D printed parts are generally near-net-shape, larger parts deviate more from this ideal due to increased material layer heights or thicknesses used to accelerate the build process. Consequently, a higher percentage of material must be removed to finalize larger 3D printed parts. In such cases, machining time holds a larger share of the process for larger 3D printed parts.

As you can see, *"CNC machining can not only be used to enhance metal 3D printing"*, **Herzig points out**. This versatile technology can be used in a variety of applications beyond Additive Manufacturing. *"CNC machines can process a wide range of materials. In addition, CNC machining plays an essential role in the production of tools and molds required for other manufacturing processes. The ability to make precise and repeatable cuts makes them indispensable for the creation of high-precision and customized tools"*, he explains.

A few areas where CNC machining is a limitation to AM

While the goal of this article is not to discredit CNC machining, we can't help but notice that there are scenarios where AM will always win.

When specifications and designs require customized parts and tooling, when the design of the part is very complex or even when part labels are required, AM will always be the way to go.

The CEO of **M&H CNC Technik GmbH** highlights these same limitations:

"CNC machining, despite being a key technology in many aspects of manufacturing, can have certain limitations when interacting with additive manufacturing, especially where additive manufacturing shows its strengths in the realization of complex structures and designs. CNC machining can be a hindrance due to its mechanical nature and limitations in tool accessibility. These limitations particularly affect the realization of extremely complex geometries, which are possible through additive processes without the mechanical limitations of CNC tools."

M&H CNC Technik GmbH on the use of both manufacturing processes

M&H CNC Technik GmbH's approach covers the entire production cycle – from consulting and engineering to 3D printing and final finishing. To deliver parts across various industries, the company relies on modern machinery that includes a Renishaw Agility measuring machine with REVO-2 technology for precision manufacturing. This equipment also helps the team minimize dynamic measurement errors and perform accurate measurements.

The company's production environment also includes an SLM 800 system which makes it possible to print large-format metal objects with an installation space of 500 x 280 x 850 mm and an automated powder removal system from Solukon.

Speaking of the industries where CNC machining and AM intertwine, Herzig notes: "*We are proud of our expertise in CNC technologies and metal 3D printing supports industries such as motor racing, particularly Formula 1, as well as the hydropower and renewable energy sectors.*

In racing, and Formula 1 in particular, the ability to quickly develop and produce lightweight and high-strength components is critical to vehicle performance and efficiency. Our expertise in topology optimization and weight reduction plays a central role in enabling teams to continuously improve and adapt their cars, often making the difference between winning and losing.

In hydropower and other forms of renewable energy, our technology supports the development and production of critical components that must withstand extreme conditions. The ability to create complex shapes through 3D printing that would not be possible through conventional methods allows us to offer more efficient and durable solutions."

[BUSINESS] THEORY MEETS PRACTICE: LEGAL CHALLENGES OF ADDITIVE MANUFACTURING IN THE AFTER-SALES MARKET

Companies see growing potential in Additive Manufacturing (AM), especially in after-sales markets with challenges like unpredictable demand and storage issues for spare parts. AM addresses these by enabling on-demand production of complex parts. Improved AM quality opens doors for diverse business cases, envisioning a future of decentralized urban production akin to Fab Cities, where collaborative information sharing on products and manufacturing methods fosters sustainability. However, legal hurdles hinder widespread AM adoption. This article navigates these issues, offering a legal assessment for practitioners, and bridging the gap between theoretical potential and practical implementation of AM in business contexts.

Based on interviews with managers from various manufacturing companies (OEMs) that embarked on the journey to implement AM, we identified critical legal issues concerning the use of AM in the after-sales market and developed three scenarios:

(1) Quality control and liability in B2C transactions;

(2) Decentralized production of spare parts and;

(3) Right to repair for businesses and IP infringement.

Scenarios and legal assessment

Scenario 1: Quality control and liability in B2C transactions

The first scenario addresses **quality control and liability concerns in B2C transactions** using AM for spare parts production. Lack of certifications for 3D printed parts raises worries about maintaining quality standards and potential liability if spare parts fail.

Example: Company A produces washing machines. A frequently used spare parts is the plastic door handle of one of their machines. In order to save costs, company A wants to use AM to produce these handles on demand. When the customer operates the replaced handle, it breaks. Sharp bits of plastic cut the customer's hand and the washing machine is damaged so that it does not close any more.

Analysis: From a legal perspective, the mentioned scenario is likely to be of particular importance to companies involved in selling consumer products. Just recently, the European Commission introduced **a proposal on common rules promoting the repair of certain goods**, e.g. washing machines and TVs.[1] Consequently, in the near future, **producers of consumer goods may face legal obligations to provide repair services for such goods, both within and beyond the scope of the legal guarantee.**[2] In addition, producers will be required to ensure that independent repairers have access to spare parts and repair-related information and tools.[3] As a result, businesses will likely be obligated to disclose the repair process of their goods. This may lead to a risk of disclosure of trade secrets concerning the production of such goods if production and repair are closely connected.

Regarding the issue of quality standards, in the past few years, there have been efforts to develop uniform industry standards in the area of AM. So far, in Germany these efforts have led to **DIN SPEC 17071**, which was published in 2019. The DIN SPEC 17071 is not an industry norm per se; instead, it serves as a guideline for implementing quality-assured processes. It represents a significant milestone as it establishes standardized requirements for AM for the very first time. This guideline should form a good starting point for businesses to develop their own quality standards.

Observing guidelines like the DIN SPEC 17071 is not only relevant for quality assurance but may also be relevant for product safety and liability. In general, technical standards are not binding law. This means that businesses cannot solely rely on compliance with existing technical standards when product safety and in particular liability for product defects are concerned. Technical standards can, however, provide an indication for the state-of-the-art in their respective scope of application. Indeed, this implies that technical standards, like those outlined in the DIN SPEC 17071, can be taken into account when evaluating product safety and security. So far, these principles only apply to true technical standards and not to guidelines like DIN SPEC 17071. As the requirements for such guidelines are relatively simple compared to true technical standards, there remains some doubt regarding the comparability of, for instance, DIN standards and DIN SPECs.

Regarding liability concerns, it's important to note that, currently, there are no distinct requirements solely targeting AM when compared to other manufacturing methods. The law does not focus on a particular technology. Instead, it is technology neutral. Generally speaking, businesses using AM will still be obligated to diligently develop, test, and oversee spare parts production to the best of their abilities, adhering to the current state-of-the-art practices, just as they would with traditional manufacturing processes. In other words: Businesses using AM are liable in the same way they are if they produce spare parts with a conventional manufacturing technology.

Scenario 2: Decentralized production of spare parts

The second scenario concerns the decentralized production of spare parts with the help of sub-entrepreneurs. In this scenario, **issues of liability for third-party behavior and intellectual property (IP)** management issues may arise.

Example: Company B wants to outsource the production of spare door handles for their washing machines as well as corresponding repair services, for instance to a local AM service provider. Company B now fears that the service provider uses the part data to produce and sell parts that do not meet quality standards and break. The service provider fears that it may infringe other's IP-rights when using the data.

Analysis: In this scenario, **issues of liability and IP management** are particularly important. The question is: How can the OEM (company B) ensure the quality of the repair services performed by an AM service provider and to what extent is company B liable if the service provider is unable to do so? Striking a balance between maintaining quality standards, protecting IP, and assuming responsibility for repair services therefore becomes a crucial challenge for the original manufacturer. In addition, there may be issues with IP protection, if the manufacturer must disclose IP-protected or sensitive information to the sub-entrepreneur to enable them to conduct repairs on their own.

Regarding the liability issue, the law remains general and not specifically tailored to technology. Therefore, **standard legal principles concerning liability apply**. This means that a company outsourcing spare part production remains accountable for any faults that stem from its sphere of influence. For instance, if the company provides inadequate or incorrect instructions, blueprints, or other essential information to the third party, leading to harm caused by a defective spare part, the company may still be held liable for the resulting damages. In essence, outsourcing spare part production does not absolve the company of its liability; it is still responsible for ensuring the quality and safety of the final product. This applies equally to the use of AM or any other manufacturing technology.

Regarding IP management and protection, companies should have licenses in place to allow sub-entrepreneurs to use their protected IP. Because IP rights are exclusive to their respective owner, the sub-entrepreneur needs this license to be allowed to make use of the corresponding IP. With regard to trade secrets, businesses should carefully consider what information to disclose. This is because trade secrets lose their protection when the owner does not take reasonable steps to keep them secret and the owner is no longer in control of them.

Scenario 3: Right to repair for businesses and IP infringement

The third scenario revolves around the challenge of repairing IP-protected goods that a company has received from its suppliers. Here, the question is whether patents or designs may prevent businesses from repairing e.g. production machines by themselves.

Example: A certain wearing part of a laser cutter needs replacement. Company C is aware that the overall machine has patents attached to it and would usually have to buy a spare part from the OEM but would like to replace the faulty part cost- and time-efficiently by printing it out on-site with a 3D-printer.

Analysis: The question of whether repairing or replacing a spare part infringes IP can only be assessed on a case-by-case basis. In principle however, some important differences between patent-protected spare parts and design-protected spare parts should be kept in mind.

In patent law, infringement depends on whether the replacement of the spare part is part of the intended use for the products or constitutes remanufacturing. In general, the exclusive right from a patent is exhausted with respect to copies of the patented product, which have been put on the market by the patent owner or with his consent. This includes the intended use of that product, in particular the replacement of e.g. wearing parts.

However, it's important to note that «repairing» should not be confused with «remanufacturing». It is generally not allowed under patent law to repair a product in such a way that it amounts to "remanufacturing". Indeed, allowing "remanufacturing" would circumvent the economic interests of the OEM protected by the corresponding patent. Therefore, courts decide this issue by balancing the interests of the patent owner against the interests of the product user on a case-by-case basis. As a rule of thumb, repairing patented products may be fine, if the relevant parts do not embody the patented invention.

In contrast to patent law, German design law offers a particular exception to design protection for spare parts used exclusively to repair complex products. in addition to the sole purpose of repair, for the exception to apply, spare parts can only be used to restore the product's original appearance. As this rule was only introduced in 2020, there are still a lot of uncertainties regarding the scope of application. As of today, there is no definitive consensus on how strictly courts will interpret the concept of restoration of the "*original appearance*".

In conclusion, when it comes to the right to repair for businesses, the current landscape is fraught with legal uncertainties. Businesses are therefore well advised to closely monitor future court decisions and developments.

Authors' notes

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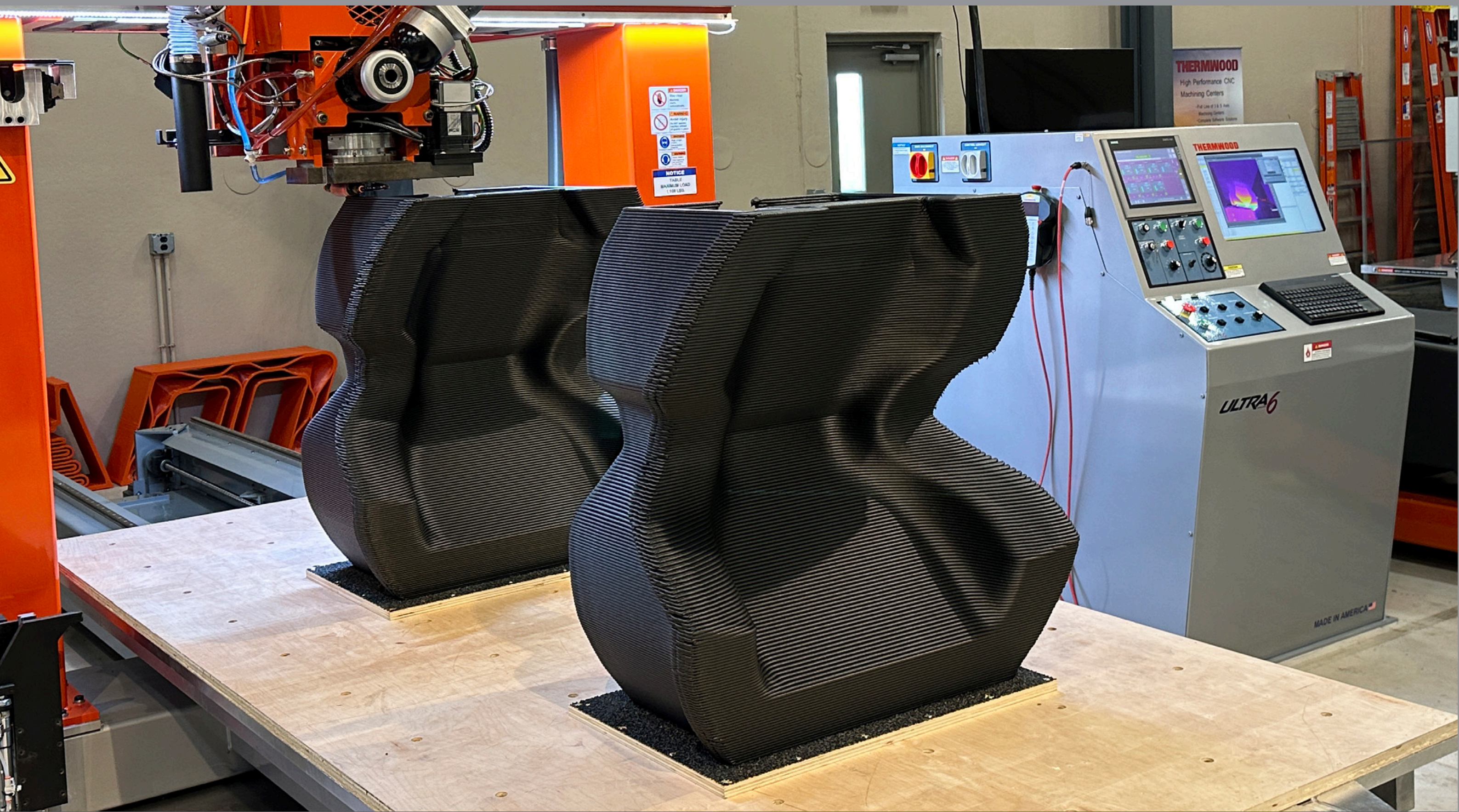
The legal assessment of these scenarios hinges on individual circumstances, highlighting the uncertainty surrounding AM in after-sales markets. Pending clearer legal interpretations, companies may use DIN SPECs to reduce liability and should be cautious about disclosing IP-protected information. Regarding the repair of IP-protected items, the principles of patent exhaustion and spare parts exceptions can be leveraged. However, current regulations lack specificity for AM, necessitating adherence to conventional manufacturing rules. The legal landscape struggles to accommodate AM complexities, compounded by varying legal regimes. Future court decisions and legislative changes will be pivotal in shaping the legal framework for this evolving industry.

This research is funded by dtec.bw – Digitalization and Technology Research Center of the Bundeswehr. dtec.bw is funded by the European Union – NextGenerationEU.



THERMWOOD'S LSAM: WHAT ARE THE KEY FACTORS OF SUCCESS?

The growing demand for large 3D printed parts implies that Additive Manufacturing users should set realistic expectations when trying to scale up their operations. While the constant comparison between Large Format Additive Manufacturing (LFAM) and desktop 3D printing processes is often inevitable, one must also keep in mind that LFAM comes in many shapes and each of these approaches requires its recipe for success. A conversation with Thermwood's ***Scott Vaal*** *helps us understand some of the key elements of success with the LSAM technology.*

Acknowledged for its CNC router technologies, **Thermwood** is one of these companies that no longer needs any introduction in the world of Additive Manufacturing. The company has made a name for itself in the field of LFAM – with its Large Scale Additive (LSAM) technology – and continues to intrigue with the recent launch of an AM process that does not 3D print.

As AM grows in maturity, it's crucial to understand the challenges inherent to each technology and the solutions that can be explored to address them. Indeed, despite the common hurdles some technologies may have, I strongly believe the way each OEM approaches the problem makes their technology more attractive or not.

This article therefore aims to understand some of the technical hurdles related to LSAM and the solutions Thermwood puts in place to address them. To do so, we will focus on technical issues that may occur at the design and materials level and during the manufacturing process.

Through his responses, **Scott Vaal**, LSAM product manager, made us realize that each item of the manufacturing value chain is somehow linked to another one – thus, they do not necessarily require individual solutions/approaches.

When technical issues at the design level affect the manufacturing process

LFAM can expand the design envelope through its ability to print several large parts in one operation. Compared to AM on a small scale, part consolidation and reduced manufacturing time are other factors that play to the strengths of LFAM.

Last year, when we discussed a strategy to increase the scale of one's 3D print with LFAM, **five focal points** had been identified to help the designer differentiate between designing for LFAM and designing for a "standard AM process": **the machine itself, the shrinking of part size during or after printing, the dependence of strength upon the print direction, the division into separate planar sections as well as the need for inserted, non-printed materials.**

Vaal first draws our attention to the fact that each part is different and should be examined for the best method to use. This means that the size of the part does not necessarily make the design more challenging. Indeed, he notes that in some cases, "*it can significantly reduce labor by incorporating as much into one print as possible, but it is not always practical to print that way. Also, there are cases where it is quicker to print the part in multiple sections rather than all in one piece. This is because you must spend at least enough time to allow a layer to cool to the ideal temperature before starting the next one. This means you may be running at a reduced feed rate to print the part in one piece but have the speed and output capability to print 4 pieces at the same time, reducing the print time by a fourth. Of course, this may mean you will have to bond or attach the parts to each other, which also takes time.*"

That being said, for the product manager, one uses the near net shape process where one typically prints much larger beads that create larger cusps between the printed layers.

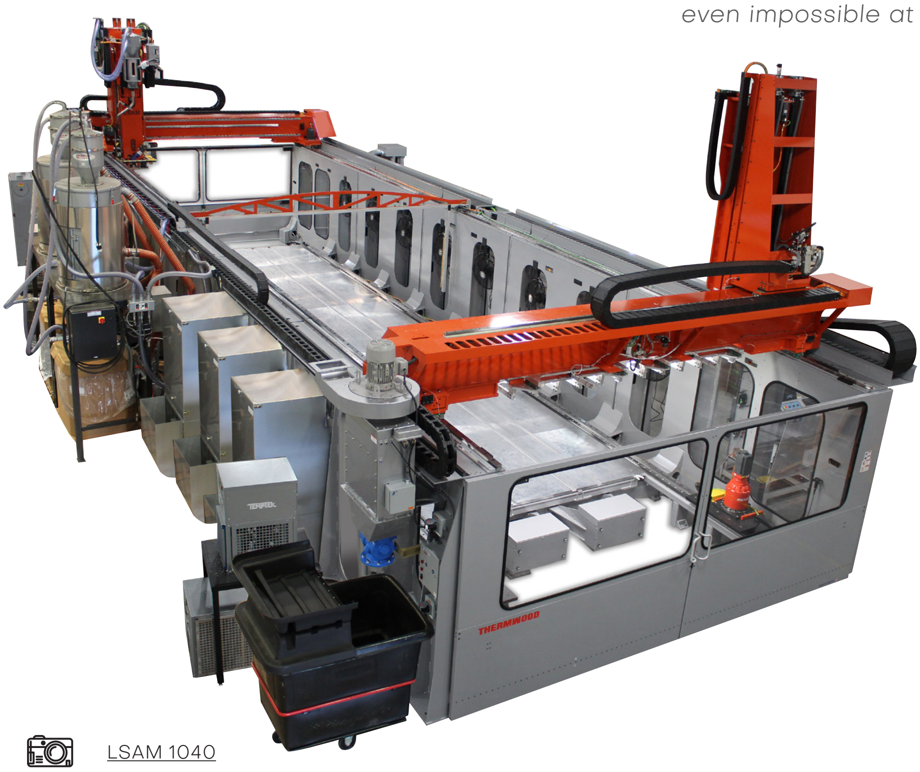
"*You will typically print slightly oversized with the intent to post-machine the surfaces that are required to be smooth and accurate, such as the face surfaces of a forming mold or tool. A lot of the time, you will stay away*

Scott Vaal with yacht mold segment.

from heavy or full infill strategies and use a hollower method with specific and pin-pointed bracing where needed. This is to keep weight down and to better control large heat differentials within the part which is especially important when using high-temperature materials suitable for autoclave tooling," he adds.

Besides these focal points, one should keep in mind that elements such as **thin walls and small features** should be avoided as much as possible. Indeed, the large bead size and difficulty with starts and stops, make these features error-prone. To address this issue, some OEMs or software providers recommend ensuring that the thickness is at least 2x the bead width when designing thin wall sections.

Using the manufacturer's **slicing software LSAM Print 3D**, users of LSAM technology can create quality print programs targeted for the LSAM and the large-scale additive. However, Vaal warns that "*it is difficult and even impossible at times to create print models that have the proper wall thicknesses needed for the large-scale planar slicing method, especially when you have undulating and complex curved flowing surfaces. LSAM Print 3D can automatically create the print path wall thicknesses for you based on the print bead dimensions you are using resulting in consistent overlaps between bead passes. It will also automatically apply the desired trim stock needed so that you do not have to modify the part geometry just to get extra print stock for machining. With its true CAD environment, you have the freedom to orient your parts any way you need and chose the print method that best fits. It has the tools and techniques to easily add pinpointed bracing and other supports to the print. LSAM Print 3D also gives you the freedom to have unique settings for different*



LSAM 1040

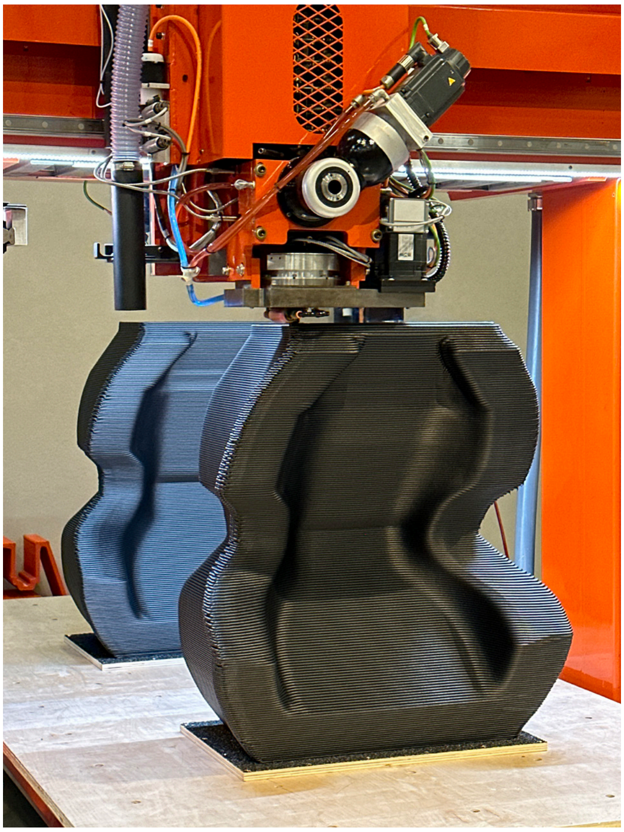
areas of the print so that you are not limited to one set of parameters to try and print the entire part. And maybe best of all, it creates the slicing and print programs directly from real CAD formats such as solids, surfaces and sheet bodies so there is no need to create an already reduced in quality .stl file just to create a print program."

Other difficulties during the manufacturing stage

Warping, temperature control and **layer adhesion** are some of the difficulties one often encounters during the manufacturing process. If you're a regular reader of 3D ADEPT Media, you probably already know that Thermwood developed a solution for temperature control.

Interestingly, the key to minimize warping and layer adhesion often lies in the **choice of materials** used during the manufacturing process. The main factors influencing interlayer adhesion include material properties, recoat temperature, warping forces, and any form of compacting or rolling of the layer post-extrusion. For some applications, materials with low shrinkage rates, and the ones filled with short strand fiber materials could be good options.

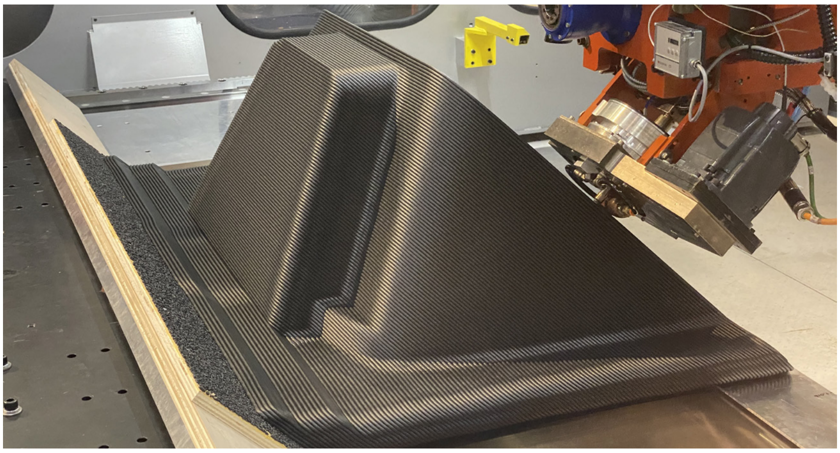
As regards warping, Thermwood's expert explains that *"it actually starts with **the LSAM's patented bead board print substrate** that provides an important strong initial tack, and then the special surface floats with the part as it cools and shrinks. Then, after the initial layers cool down it holds strong throughout the entire printing process, preventing distortion and stresses that build in other substrates. Also, achieving and maintaining optimal temperatures during the entire print process is important for controlling warp, but maybe more important for providing proper layer adhesion. As [stated above],*



*Thermwood solves this issue with its **patented Layer Time Control feature built into the LSAM control system** which dynamically controls and maintains proper temperature conditions. Equally important to layer adhesion is the **active compaction you get from the LSAM's patented compression following wheel** which greatly enhances interlayer bonding and provides the best results for lateral bead to bead solidity."*

Consistency, "one of the best traits of LSAM".

While inconsistency in material properties is often one of the key issues to address in a "standard" AM process, users of Thermwood's LSAM should not face any issues in this regard.



"Our patented Melt Core system delivers the most precise and consistent material output possible and with the patented compression following wheel you get the most accurate bead dimensions and consistency in the printed composite microstructures. Being consistent is especially important when printing high-temperature autoclave tooling where we must accurately compensate for anisotropic CTE and other shape changes. This also means we must have material suppliers that can provide consistency between lots of materials. Luckily, we have several suppliers that we can trust to do just that", Vaal states.

If this article discusses some of the most widely encountered issues faced during a manufacturing process that involves LFAM, it is fair to say this list is not exhaustive. We strongly believe that the more AM users assess Thermwood's LSAM, the more we will outline specifications and learn lessons that could help ensure a successful product development.

As Vaal points out: *"Thermwood is always looking to improve its products, processes and software. We are never sitting still, so it's hard to tell what may be right around the corner for LSAM innovations. We are constantly working internally and with customers and research facilities to come up with innovative solutions and improvements."*

This content has been produced in collaboration with Thermwood. All images: courtesy of Thermwood.

FOUNDRY LAB: "MOM WAS WRONG. YOU SHOULD PUT METAL IN THE MICROWAVE; IT WON'T GO BANG!"

*It's probably very cultural but I grew up in an environment where I was taught that our parents are always right – especially moms. They simply know best. Imagine my surprise when at Formnext 2023 I stumbled upon **Foundry Lab**, a company that was bold enough to state loud and clear "Mom was wrong". Of course, I had to stop by their booth to tell them they were wrong to state such a thing - no matter what their reason was; but I needed to understand first what led to such a bold statement. It took me a few months and a recent conversation with founder and CEO **David Moodie**.*

We may have discovered **Foundry Lab** last year when it debuted on the European scene but the company was founded in 2018. It turned out that Moodie was running a design consultancy before founding his company and he was frustrated with their ability to only prototype plastic parts and not metal castings.

"My clients were falling through this huge gap in manufacturing – die-castings are impossible to prototype. I got frustrated with the inability to test our designs in the production material – so I decided to fix the issue myself!", he said.

It looks simple but it's truly not. If I was seduced by their marketing tactic, the more I read about them, the more I found subject to debate.

What does Foundry Lab do?

Simply put, the company headquartered in New Zealand leverages the strengths of traditional casting and combines it with Additive Manufacturing and microwave technology to produce metal parts.

If my understanding is correct, the company's strategic thinking is based on a harsh truth: it's difficult – sometimes impossible to 3D print a casting. Most importantly, the latter should not be confused with a metal part as there are two different things.

To fill that gap between casting and 3D printing, the team has developed a solution called *"Digital Metal Casting"*.

Moodie explains how the solution works: *"We approach casting a little differently – we 3D print molds in a ceramic powder, insert a slug of metal into the mold and then heat the mold. The slug melts and fills the cavity. The outcome is a casting with the same alloy and geometry as your production casting."*

The controversy might arise when Foundry Lab said *"Stop printing prototypes"*. Something that the founder clarifies: *"Essentially we were saying that "If your parts will be cast in production - they should be cast in prototype." Printed metal parts share the same color as a casting but that's about it. You cannot get the data you need from a print."*

Castings. Credit: Foundry Lab.

How does it work?

Well, the first explanation I received from **Hester Tingey** (the company's marketing manager) at Formnext reveals a **four-step process** that includes: a 3D printer based on binder jetting, a depowdering station, **and a** microwave furnace – all of this working with a dedicated software solution; all supplied by Foundry lab.

The 3D printer fabricates a tooling in a proprietary ceramic using a proprietary binding agent. That part undergoes a microwave curing process before going to depowdering.

The metal casting process is carried out without the need to pour molten metal. Solid metal, either in the form of a disc-shaped medallion from Foundry Lab or any other solid piece, is placed into the mold, which has a reservoir to hold this raw material. The microwave furnace doesn't directly melt the metal; instead, it heats the ceramic mold to a temperature that melts the metal. The molten metal flows into the mold, solidifies into a cast part, and then requires the removal of excess material, such as flash, just like any other casting.

The entire process yields 5 main benefits that Moodie lists below:

- Production quality castings without any casting knowledge.

  We recognized that the market for casting in the US/EU is booming but foundries are still closing down. The issue is that we have lost the workforce with the technical knowledge to work in the foundry. Foundry Lab's goal is to digitize casting – to allow an untrained operator to achieve quality castings.

- Safety: The mold goes into the furnace cold and comes back out cold. This is hands-off casting. Think of a paradigm shift from a dark foundry with fire and smoke to a clean room environment

- Any geometry: By digitizing the mold making (3D printing) we have complete geometric freedom. The way we cast also allows thin wall – so, essentially we can achieve anything that die-casting could have done – without the pressure, steel molds or casting experts.

- Speed: The system can turn around a part in under 24 hours. Castings tomorrow. (Compared with the 6-18 months that the industry is currently dealing with)

- Cost: This is a complicated one – this system is orders of magnitude cheaper than casting for short runs. There is a crossover when you get into higher quantities. But the initial outlay on tooling is what stops prototype/short-run castings in the first place.

Speaking of areas that could be improved in this process, the founder mentions bigger sizes and higher temperature alloys – both of which are being improved by the company.

Key applications

"We have parts on cars, on the road already! The reason is that the parts are functionally equivalent to production castings. The applications we are seeing at the moment are casting R&D, legacy part production without requalification (supply chain resiliency) and short run/bridging between trials and mass production", Moodie told 3D ADEPT Media when asked about the key applications that demonstrate their technology potential.

Furthermore, the development of applications is fostered through industry collaborations and Foundry Lab's development is no exception to this rule. One development effort that is worth mentioning is seen with global power management company Eaton that relies on the Digital Metal Casting System to cast aluminum parts in weeks rather than months. Those parts include stainless steel pins, and are described as *"a technological advancement that is not possible with traditional 3D printing."*

Image credit: Eaton & Foundry Lab

Image credit: Eaton & Foundry Lab

«Eaton is often faced with the challenge of applying AM to legacy applications because changing the process and/or material is too big of an engineering hurdle,» says **Cameron Peahl**, Additive Manufacturing Manager at Eaton's Additive Manufacturing Center of Excellence, *«In this example, Foundry Lab's technology provides a solution for us to leverage the speed and agility of Additive while maintaining the conventional casting method and material, even including the cast-in-place steel pin. This is a huge step forward in our AM journey.»*

Aware that the goal of most users is to **achieve both series and mass production**, Moodie confirms that they *"don't want to get stuck where 3D printing is right now."* *"We are focused on production – this is what is needed to fix the capacity shortfall in industry today."*

However, in the meantime, the company's near-term steps are to **complete the digitization of the entire casting process** and **qualify all the key casting alloys** to allow the system to fit seamlessly into manufacturing.

RAPID + TCT 2024 EXECUTIVE PERSPECTIVES KEYNOTE SERIES ANNOUNCED

For the first time ever, the event will feature an Executive Perspectives Keynote Series, featuring 15 industry luminaries and thought leaders from across the global AM ecosystem.

RAPID + TCT 2024 in Los Angeles, North America's largest additive manufacturing (AM) and industrial 3D-printing event produced by SME and UK-based Rapid News Publications Ltd., owners of TCT, from June 25-27, announced its Executive Perspectives Keynote Series today, featuring 15 industry luminaries and thought leaders from across the global AM ecosystem. Attendees will gain insights and inspirations on the future of AM from engaging panel discussions among the industry's leading voices as this inaugural program opens on the Main Stage each morning.

The Executive Perspectives Keynote Series will cover AM's hottest topics, including its:

· Biggest challenges and opportunities

· Applications driving adoption and ultimately moving to full-scale production

· Convergence with AI and automation

· Trends on the horizon to enrich human health and wellbeing

· Supply chain impacts

· State of sustainability and its long-term potential

«At a time when AM has reached a critical inflection point in its growth and evolution, the Executive Perspectives Keynote Series gives RAPID + TCT attendees access to the most powerful minds shaping the global additive manufacturing landscape,» said **Bob Willig**, executive director and CEO of SME. *«Convening these leading voices in this first-of-its-kind series is a demonstration of SME's unwavering commitment to advancing AM technologies and to providing a platform where innovators can come together to chart the course for the future of manufacturing. I'm looking forward to seeing the series continue and evolve at RAPID + TCT 2025 in Detroit and RAPID + TCT 2026 in Boston.»*

Presented daily at 8:30 a.m. on the Main Stage, the Executive Perspectives panel discussions are moderated by Laura Griffiths, head of content, The TCT Group and feature the following industry leaders:

- **Savi Baveja**, President of Personalization and 3D Printing, **HP**

- **Alain Dupont**, Chief Commercial Officer, Colibrium Additive, a **GE Aerospace Co.**

- **Ric Fulop**, Co-Founder, Chairman and CEO, **Desktop Metal**

- **Charlie Grace**, Chief Commercial Officer and President of the Americas, **Nikon SLM Solutions**

- **Jeffrey Graves**, PhD, President and CEO, **3D Systems**

- **Marie Langer**, CEO, **EOS GmbH**

- **Maxim Lobovsky**, Co-Founder and CEO, **Formlabs**

- **Nils Niemeyer**, General Manager, **DMG MORI**

- **Avi Reichental**, Co-Founder and CEO, **Nexa3D**

- **Victor Roman**, PhD, Managing Director, **ARBURGadditiv**

- **Michelle Sidwell**, Chief Commercial Officer, **Velo3D**

- **Yoav Stern**, CEO and Member of the Board of Directors, **Nano Dimension**

- **Shai Terem**, President and CEO, **Markforged**

- **Fried Vancraen**, Chairman of the Board, **Materialise**

- **Yoav Zeif**, PhD, CEO, **Stratasys**

As RAPID + TCT returns to the West Coast in this year, attendees have the unique opportunity to be part of the evolution of AM, which is predicted to grow at a compound annual growth rate of ~14% from 2023-28 (AM Power). Accelerated adoption among a wider cross section of the manufacturing industry is driving AM innovation and efficiency forward, while RAPID + TCT is propelling the AM industry to the next level by fostering commerce, expanding awareness, championing the community and through expert-level knowledge sharing.

Editor's notes:

3D ADEPT is a media partner of Rapid+TCT 2024. This content has been produced by SME and RAPID + TCT.

For 35 years, SME and RAPID + TCT have defined the crucial role of Additive Manufacturing and empowered the establishment of an industry that continues to conceive, test, improve and manufacture new products at a faster, more cost-efficient pace. In 2017, the two industry leaders in 3D-technology events, SME and the Rapid News Publications Ltd., partnered to produce the annual RAPID + TCT event. For users and suppliers alike, the event is the premier destination for those who provide technology and those who need to understand, explore and adopt 3D printing, additive manufacturing, 3D scanning, CAD/CAE metrology and inspection technologies.

Event

Materials Development in AM

Of the challenges facing adopters of additive manufacturing (AM), finding the right material continues to rank highly. Material choice impacts everything from the design envelope to the end-of-life considerations across metals, polymers and other non-metal processes. As such, materials remain a central part of the ongoing research and developments in AM.

An excellent way to learn more about these developments is RAPID + TCT, North America's largest additive manufacturing and industrial 3D printing event. This year's edition takes place Jun 25-27 in Los Angeles, California. To obtain a complimentary Expo Pass as 3D Adept's guest, register with promo code RPMS. Keep reading to learn more about materials development in AM, and how the topic is well covered at RAPID + TCT 2024!

KEYNOTE

The New Space Race: How Relativity Space is Revolutionizing Rocketry with AM
Tuesday, June 25, 2024 1:00 PM to 1:45 PM

High-performance polymers open new applications

In line with the overall trend of AM becoming a 'production' technology, demand for high-performance polymers is driving development cycles. Strength, chemical and heart resistance and biocompatibility are key areas for new materials looking for traction in the big three industries: aerospace, automotive and medical. Of these, medical and healthcare applications are the most diverse and numerous, spanning everything from drug discovery to patient-specific devices and pharmaceutical delivery systems.

Metals are driving production

Metal AM centers around the powder bed and directed energy deposition processes. While the inherent abilities of AM in creating complex geometries and consolidating parts have driven adoption, new applications are looking to maximize the materials flexibility of the processes.

Of particular interest are materials that are impossible or hard to process through other means. Refractory metals for example offer excellent mechanical properties, chemical and heat resistance but are hard to manipulate in traditional manufacturing processes. Developments in AM mean that where refractories can be manufactured they can be used — finding immediate applications in space and aerospace.

Multimaterials are also an area of promise, including combining multiple metallic materials into a single part, especially where grading from one to another is required. Combining materials with complementary properties, or minimizing the use of more expensive alloys to the areas they are needed most opens up huge potential for manufacturers.

One to watch

Who? Marvin Uhlig, Research Intern, Fraunhofer USA

What? Developing a Co-Sintered Copper-Ceramic Feedstock for Thermal Applications Using Fused Filament Fabrication

When? June 25, 2024, 10:00 - 10:30 AM

Sustainability is front and center

Materials are a key driver of the sustainability of AM parts. While the processes themselves are mostly dependent on the energy source (I.e., coal-powered vs hydroelectric), materials' span from extraction, refining, transport and recyclability creates opportunity to affect meaningful improvements.

Any extraction of material from the earth will have an impact, so while strategies for reducing this impact are ongoing, recycling and re-use of existing materials is at the fore of materials advances. The more difficult and expensive the virgin material is to create, the greater the opportunity for recycling and circular supply chains to disrupt the status quo. For materials such as Ti64, current waste streams have the ability to meet a significant proportion of manufacturers demand by deploying circular supply chains.

One to watch

Who? Robert Higham, Founder & CEO, Additive Manufacturing Solutions Ltd

What? Recyling & Reusing Aerospace Parts by Converting into Powder for Additive Manufacturing - A Lessons Learned & Technical Summary

When? June 25, 2024, 11:30 AM - Noon

Materials matter

While machine launches often steal the headlines at industry events like RAPID + TCT, the materials research and development is what will ultimately drive forward the adoption of AM in cutting edge applications. Equally, it is the materials that offer manufacturers the greatest opportunity to improve their sustainability both through the sustainability of the materials themselves, and through the new use cases novel materials will open up.

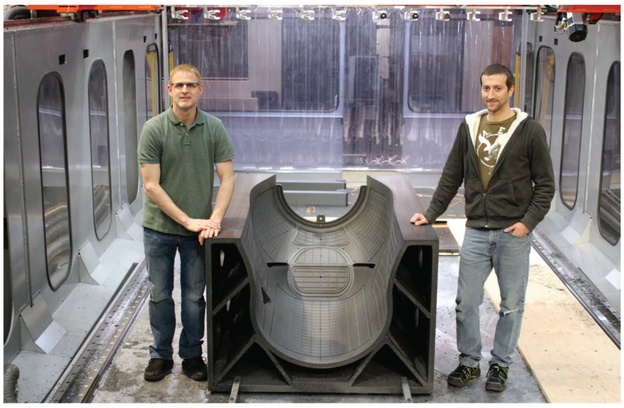
To obtain a complimentary Expo Pass to RAPPID + TCT 2024 as as 3D Adept's guest, register with promo code RPMS.

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.



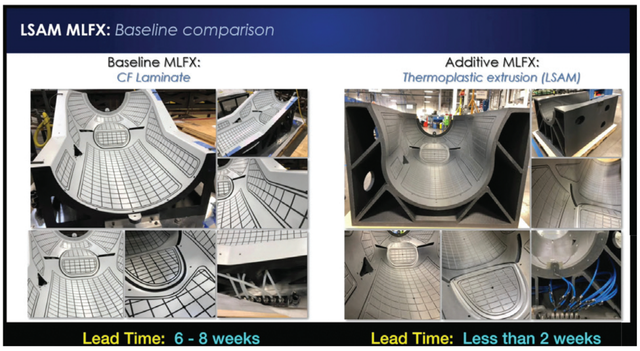
Cost Savings of around $50,000 vs traditional methods

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

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

GENERAL ATOMICS AERONAUTICAL



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

THERMWOOD

www.thermwood.com

800-533-6901

Industry events

2024

Stay up-to-date with the latest additive manufacturing industry events, conferences, exhibitions and seminars.

GERMANY	**USA**
FORMNEXT 19-22 NOVEMBER 2024 FRANKFURT www.formnext.com	**RAPID + TCT** JUNE 25, 2024 TO JUNE 27, 2024 LOS ANGELES CONVENTION CENTER, LOS ANGELES, UNITED STATES www.rapid3devent.com
HANNOVER MESSE 22-26 APRIL 2024 HANNOVER www.hannover messe.de	**SPACE TECH EXPO US** 14-15 MAY, 2024 LONG BEACH, CA www.spacetechexpo.com
RAPID.TECH 3D MAY 14, 2024 TO MAY 16, 2024 ERFURT TRADE FAIR, ERFURT, GERMANY www.rapidtech-3d.com	**SWEDEN**
SPACE TECH EXPO EUROPE 14 – 16 NOVEMBER, BREMEN www.spacetechexpo-europe.com	**EURO PM2024 CONGRESS & EXHIBITION** SEPTEMBER 29, 2024 TO OCTOBER 2, 2024 MalmöMässan Exhibition & Congress Center, Malmö europm2024.com
SPAIN	**CANADA**
ADDIT3D 2024 4-7 JUNE, 2024	**FABTECH CANADA 2024** JUNE 11, 2024 TO JUNE 13, 2024 The Toronto Congress Centre (South Building), Toronto, United States canada.fabtechexpo.com
METAL MADRID 2024 20-21 NOVEMBER, 2024	**MORE EVENTS WILL BE ADDED LATER !**
UNITED KINGDOM	
TCT 3Sixty JUNE 5, 2024 TO JUNE 6, 2024 NEC, NATIONAL EXHIBITION CENTRE, BIRMINGHAM www.tct3sixty.com	

AMSC 2024

The International Catalogue of AM Solutions

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 | 3D PRINTERS | MATERIALS

More info at « www./3dadept.com/contact-us/ » | contact@3dadept.com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your ticket!
WE SPEAK
MEDICAL TECHNOLOGY!
Immerse yourself in the world of the medical device supply sector at MedtecLIVE 2024. We speak your language! Meet specialists who understand your challenges and offer tailored solutions. Discover trends, find alternative suppliers and ensure a stable supply chain. Attend presentations and discussions to learn how companies are tackling today's challenges and stay up to date with new manufacturing technologies and market trends.
Automation, digitalization and the circular economy will be in the spotlight, as will the EU MDR (Medical Device Regulation). Meetings can be held efficiently thanks to short walking distances in Messe Stuttgart's largest hall. Use our digital tools to prepare and network to ensure your visit is a success.
Join the in-depth discussions – BE PART OF IT
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