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3D ADEPT MAG

3D PRINTING

LARGE FORMAT ADDITIVE MANUFACTURING : MATERIALS, SOFTWARE AND COSTS

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Table of Contents

Hello & Welcome

When size matters

Yes, size matters. But, not in ways that may first come to mind. In Additive Manufacturing, the prevailing myth is that it can only print small and complex parts. Yet, those parts are not usually essential when it comes to building parts for the land, sea, air, architecture or construction, aerospace and space industries.

The fact is, Large-Scale Additive Manufacturing/Large-Format Additive Manufacturing is a niche that requires one to rethink everything from materials to design process to potential adjustments of one's production facility. For those of you who might think «it's also the case for other AM processes», let me tell you this: we've found a dozen reasons that justify our argument.

The leap from small to large format 3D printing comes with a share of challenges that go beyond the technology's technical capabilities to encompass financial and human resources. These challenges seem to be exacerbated when trying to scale production, emphasizing how this AM holy grail remains of paramount importance irrespective of the technology used.

Nevertheless, there is a market for very large 3D printed parts, and this edition of 3D ADEPT Mag attempts to demonstrate how diverse and impactful it is.

Kety SINDZE
Managing Editor at 3D ADEPT Media
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Significant Cost Savings on Additive Tool

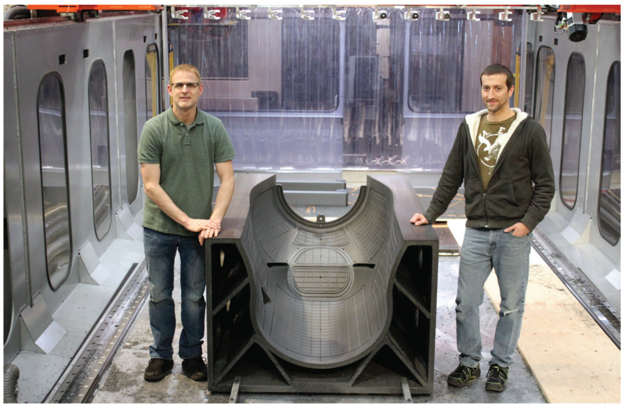
Partnership between Thermwood and General Atomics

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

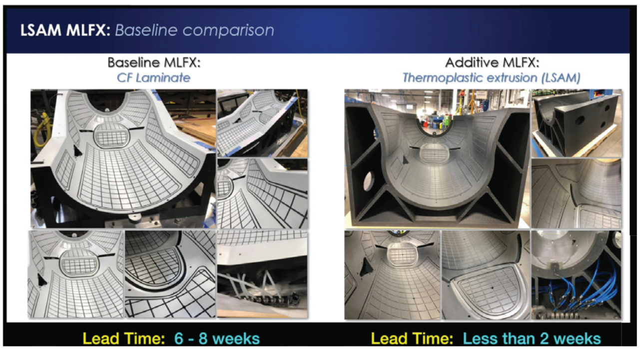
Total lead time for the part decreased from 6-8 weeks to less than 2 weeks by utilizing the powerful LSAM system.



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



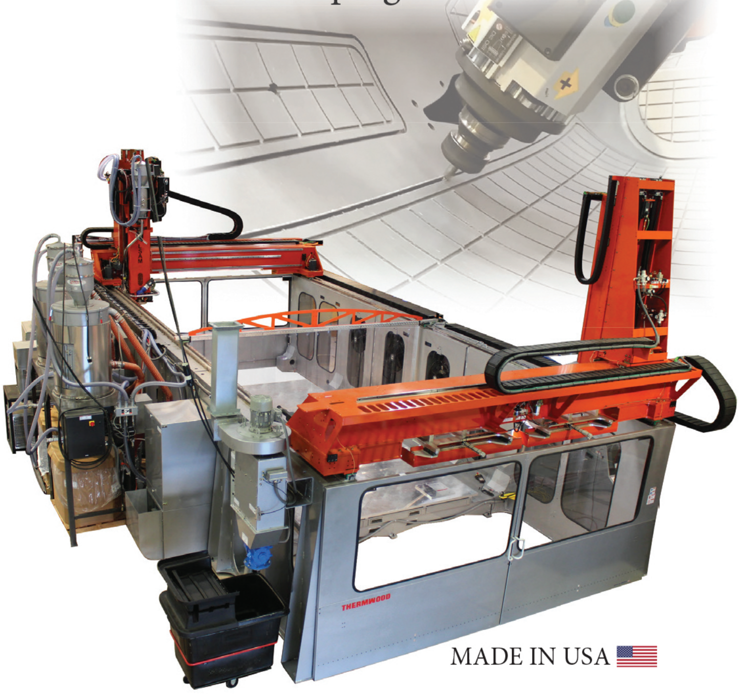
LSAM MLFX: *Baseline comparison*

Baseline MLFX:
CF Laminate

Additive MLFX:
Thermoplastic extrusion (LSAM)

Lead Time: 6 - 8 weeks

Lead Time: Less than 2 weeks



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

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Large - format Additive Manufacturing : Materials, Software and Costs

Most adopters of Additive Manufacturing (AM) share the same dream: being able to achieve scalable, (high-volume) production. Here is the thing, to make this dream a reality, most industrials often have in mind the use of machines with build volumes around 600 × 300 × 600 mm (23.62 × 11.81 × 23.62 inch). As Large-Format Additive Manufacturing (LFAM) is gaining momentum, we are entitled to ask ourselves how and/or if LFAM can also be considered a viable production candidate.

While everyone agrees that Large-Format Additive Manufacturing (LFAM)/ Large-Scale AM is about size, the specifications of applications' size have always been subject to interpretation. As you may have seen above, we have already disqualified machines with build volumes around 600 × 300 × 600 mm (23.62 × 11.81 × 23.62 inch) as we are looking to explore the production candidacy of machines that can produce yacht hull molds, autoclave tooling, massive 3D printed torches like this one, life-size furniture, boats or even houses. The key measuring element is therefore the **ability of the 3D printer to produce large components in a single print run**, as opposed to producing several parts that need to be assembled.

The size issue cleared up, let's remember that as any manufacturing technology qualified for an industry 4.0 environment, LFAM also aims to scale up manufacturing operations while taking into account speed, precision, mechanical strength, ease of customization, etc. For such industrialization to happen, technology providers need to provide clear indications on how to address the challenges that slow down the adoption of the technology. Among the wide range of technical processes that can achieve large-scale applications, one tends to realize that the main challenges to address often turn around three key aspects: **software, materials** and **costs**.

The dossier below aims to help industrials:

- Understand the major differences between designing for Large-Format AM and designing for a "standard AM process"

- The key material considerations that could open up (new) large-scale AM applications

- Understand the common pitfalls of large-scale additive manufacturing and where exactly the cost consideration stands in the midst of all of this.

To discuss this topic, we have relied on the expertise of **Justin Ferguson**, Autodesk Senior Solutions Engineer for the software part, **Kyle Calvert**, Composite Applications Engineer at Ingersoll Machine Tools for the materials and costs standpoints, as well as **Andy R. Bridge**, Director of Business Development at Additive Engineering Solutions, LLC for the user perspective.

Image via Autodesk. Complete view of the bridge

Designing for LFAM

As detailed in our 2023 International Catalogue of AM Solutions, we identified three types of large-scale AM technologies – each of them having a wide range of sub-processes:

- **Extrusion-based technologies** where one finds pellet material extrusion (FGF) and filament material extrusion (FFF) processes,
- **Powder processes**, a category that includes powder-bed fusion approaches, binder jetting and material jetting processes and even cold spray processes,
- **And Directed Energy Deposition** (DED) processes where we identified Electron-beam additive manufacturing (EBAM), Laser deposition welding (LDW) and Wire arc additive manufacturing (WAAM).

Interestingly, even though some powder-bed fusion processes can fabricate parts larger than one cubic meter, using multiple lasers and larger, multi-area powder bed, the biggest breakthroughs in terms of size come from a growing adoption of DED and in particular WAAM-based processes.

As far as design is concerned, knowing the **different design tools in the DfAM toolbox** – **as explained in PP 30-32 of this issue** – is one thing, making wise use of them is another one, especially when you know that each AM process and each machine comes with its share of challenges.

While he acknowledges the peculiarities of each machine and each process, Justin Ferguson from Autodesk outlines that *"one task that is universally difficult, independent of process, is recognizing areas (during the design process) where there may be a collision of the printing hardware with sections that have already been printed, or non-printed items."*

The good news is that when one uses an LFAM process, one has the ability to 3D print in one piece, which eliminates assembly labor, speeds up production, and increases structural integrity because there are no joints or seams.

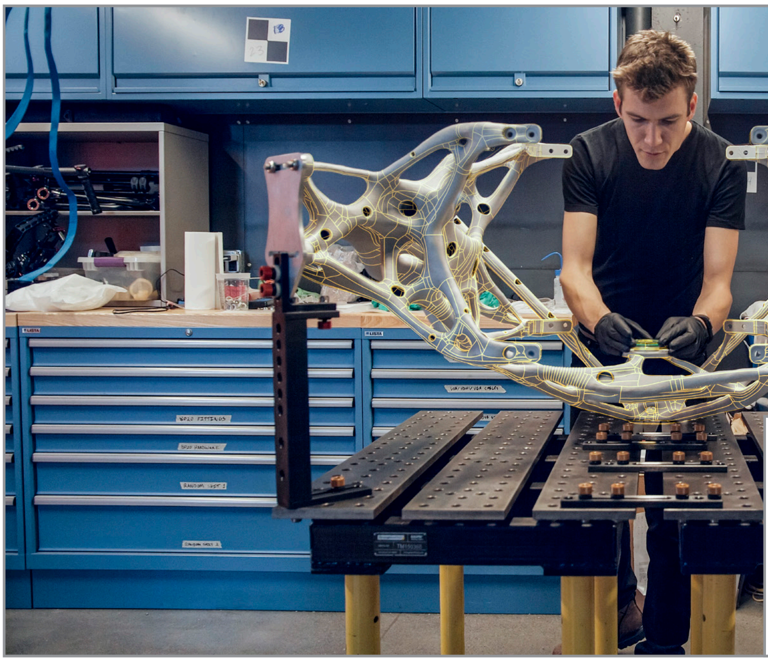


Image via Autodesk. Legend: In this collaborative research project, Autodesk and NASA's Jet Propulsion Laboratory (JPL) tested the use of generative design to make a concept space lander that is 35% lighter than a traditional design. The software allowed the team to leverage three different manufacturing methods (casting, additive and subtractive manufacturing) to produce the lightest and strongest design, which will be critical for future space travel.

How do you develop a strategy to safely increase the scale of your 3D print ?

Ferguson identifies **five focal points** that may help the designer to differentiate designing for LFAM from 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**.

He details the reasoning behind each of these considerations below and shares a couple of tips to address issues like shrinking during and/or after the printing process:

"Depending on the LF-AM process, metals (DED, Directed Energy Deposition), plastics (FFF, Fused Filament Fabrication/FGF – Fused Granule Fabrication), aggregates (clay and concrete), and others, different strategies for design become critical to adopt.

1- In small-scale additive, we normally have a fixed machine with a single coordinate system and a fixed build envelope. With ***large-scale, we might be using a robot system, or printing on top of another part****, but usually, we don't have a fixed coordinate system or a fixed build volume. While desktop printers often only move in three axes, large-scale printers often have more axes of motion,* *whether that's to move on a track or tilt the tool head. These large format processes performed with multi-axis-capable machines add the ability to create features that are not dependent on overhang angle. This enables us to think outside the 'regular AM process' of design for additive manufacturing (DFAM). For example, building features on features, and designing without support structures becomes possible, but can introduce new complexities such as how to slice, surface prep (when building features on features), etc.*

2- Most LF-AM processes will see a ***shrinking of part size during or after printing*** *due to conditions such as the cooling of metals and thermoplastics or drying/curing for aggregates and thermosets. Also, as LF-AM prints increase in size, upper layers 'squish' lower layers if they aren't cooled or cured adequately.*

If, by design, there is a stop during printing and then restart, such as printing a new feature, or allowing for adequate cooling, the part size and shape are likely to change before we continue.

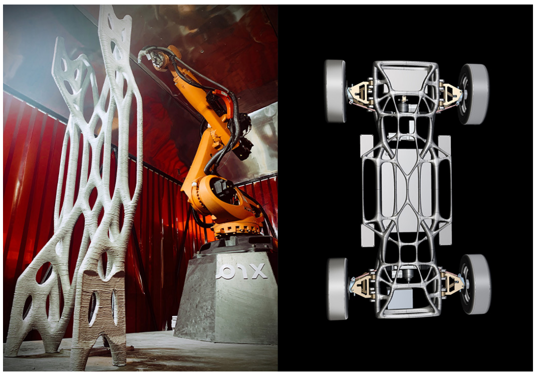
In Autodesk's Birmingham Technology Centre we use a thermoplastic pellet extruder fitted to a Kuka 6-axis spherical wrist robot. During one project, we determined that the best way to accurately continue was to over-print and then cut away to a known height using a milling spindle, then restart printing. This is a major difference for LF-AM, because separating the model into print sections, determining overbuild amounts, then the machining amount, all need to be accounted for in the design process. If hybrid (additive and subtractive in the same setup) is not an option, then the shrink amount of the print sections is very important, as is determining where to stop and for how long, so the shrink is predictable and compensable.

3- Another area that LF-AM is quite different from 'regular AM' relates ***to strength being dependent upon the print direction****. In a laser powder bed-style machine, for example, the pattern that the laser sinters can change the grain structure and resulting strength. One of our customers, using a powder laser machine, found they could achieve a better grain structure if the whole part was created in one continuous path. The desired grain structure can propagate along continually with consistent speed and constant heat.*

4- When creating complex geometry such as a bent tube or other complex shapes, a decision could be made to ***divide into separate planar sections****, each with a different build direction – like building a tube with wedge sections. Or an engineer might decide to change the build direction on every layer, and modulate the speed, feed, or other process parameters to achieve a non-planar layer shape.*

5- When considering some of the largest prints, such as homes, ***there is a need for inserted, non-printed materials.*** *Windows, doors, HVAC, electrical, posts, beams, and other items may need to be accounted for in the DFAM process. If the non-printed materials are integral for the structure, such as posts or beams, determining when to stop a print to then insert these, and make sure they won't cause collisions with the deposition equipment later, are required steps that are unique to this LF-DFAM use case."*

What happens when your part is just too large for even the largest machine?


PIX Moving, an Autodesk customer using AI and 3D printed vehicle frames to create a whole new kind of versatile electric vehicle and disrupt the automotive industry. Image: courtesy of PIX Moving and Autodesk

Needless to say that the larger the final part is, the more challenging the print. The only option at this point consists in splitting your model into 3D printable components that you will assemble thereafter. Splitting your model directly in your CAD software is a great idea as one can directly design alignment aids, avoid cuts that go directly through specific areas and select cuts that are not located in fragile areas of the print.

For **Ferguson**, *"physics really starts to play a role as parts get bigger. For instance, a wall structure will need to be designed differently if your bead is 1cm wide vs 15cm wide. Think about the weight of the part as layers increase. For DED and other processes, bottom layers can squish or wall structures can even buckle with the tremendous weight of large parts.*

In the case of FFF/FGF, if printing in a non-vertical or non-planar orientation, as weight extends out there is the possibility of both compression and tension in layers. This could cause failure in prints and should be accounted for in the design process, which is much more difficult as part size increases.

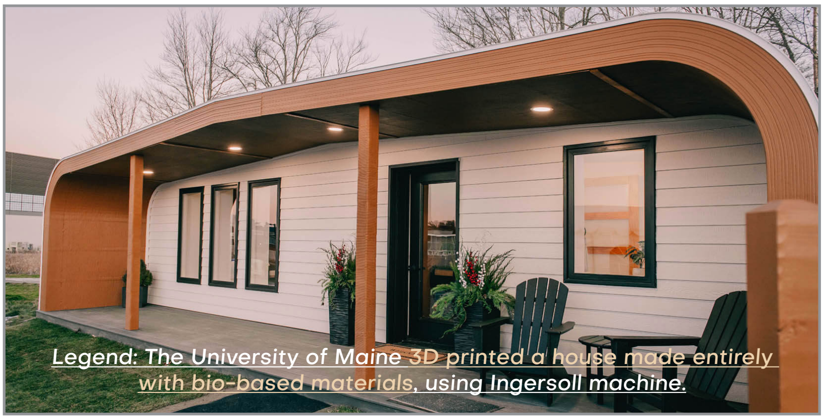
Lastly, determining if support structures are needed and how they should be applied really becomes quite a difficult design question with large final part sizes, like printing buildings or rockets. If there are supports, they have usually been designed very specifically."

Key material considerations for LFAM applications

Materials and costs have always been mentioned as the biggest challenge in AM – no matter what technology is used. These challenges are the same if not exacerbated for LFAM as applications span different technologies.

As far as materials are concerned, surface roughness, damage tolerance, inferior fatigue & tensile strength, etc. are a number of problems that may affect a 3D print. Those problems are often linked to an inconsistency in material properties. **Whatever the process used, these problems can still occur when fabricating LFAM applications.**

"There can always be a defect. Sometimes, when you're printing, it's hard to see where the defect is. For a lot of parts we make – most of our parts are for the aerospace industry –, we make a mold or a hot forming tool; those parts that will allow the customer to create the end-use part. And when those problems occur, you add a factor of safety. So, even if there is a defect that alters material properties, you still have a strong enough part at the end; and we combine that with non-destructive testing," **Calvert**, Composite Applications Engineer at Ingersoll Machine Tools states. According to Ingersoll's expert, there is a certain amount of deflection that is allowable in a mold during the fiber laying process that is allowable to still produce a high quality part. Since their printing process aims to replace metal tooling with large format additively manufactured polymer tooling, the manufacturing process should withstand the forces of the layup process without deflecting (temporarily changing shape) over a certain amount. This deflection can be measured in order to quantify if the tool meets the requirements needed for this manufacturing method.


Legend: The University of Maine 3D printed a house made entirely with bio-based materials, using Ingersoll machine.

On another note, it's also possible to identify these defects as they occur by tracking the process parameters using thermal and vision systems. However, because it's such a new technology, most machine manufacturers in this area are still in the data collection phase. As we get more data on what happens during the print process, we could use machine learning to identify the parameters that needed to be adapted and address the problem to predict future errors," **Kyle Calvert** adds.

Keep in mind that Calvert shares his expertise here with polymers in mind – especially **pellets** used for Ingersoll's polymer extrusion technology whose build volume is greater than **one cubic meter.**

Needless to say that solutions to address material inconsistency vary from one manufacturer to another, and from one technology to another.

Additive Engineering Solutions, LLC is currently using LFAM for series production. While he didn't exactly precise the type of LFAM they harness, **Andy R. Bridge** explains they currently *"rely on statistical-based process control during the LFAM printing process followed by dimensional and sometimes vacuum integrity inspections"* to address these inconsistencies.

Moving forward, materials that will bring a substantial advantage in terms of **performance** and **resistance** (to UV and water in particular) are likely to open new applications in the LFAM segment. To these items, **Calvert** adds **materials with lower cost** and materials with **better isotropic properties.** The Composite Applications Engineer lays emphasis on the fact that some of these requirements can be more stringent for certain users – like aerospace part manufacturers.

"For aerospace part manufacturers, the Coefficient of Thermal Expansion (CTE) is not quite as good as metals because the material is a polymer. When you're trying to put the mold into an autoclave process, it works more than metal would. The better those engineering polymers get, the closer we get to replacing metals in mold making," Calver notes.

Apart from these engineering requirements, it should be noted that recycled/repurposed/upcycled material formats are the next areas of interest that manufacturers would like to see expand.

A hard time for plastics, in general

"Plastics in general have a hard time being outside," Ingersoll points out. *"Material experts have been working on adding additives into the plastic so that it can better withstand UV and water, but until we get a plastic that can last many years outside, under the sun or rain, it's going to be harder to adopt LFAM at a wider scale."*

In addition, **cost** is another key item that prevents a larger adoption of LFAM. For our expert, machine manufacturers in this niche segment currently compete with conventional manufacturing processes, wood or other cheap prototyping methods of making parts.

This means that:

- If production ramps up and the price of materials drop,

- If newly developed engineered parts with better material properties enable the manufacture of end-use parts and not just molds or tooling,

There is a great chance that more industries adopt pellet-based LFAM technologies.

Materials used in other processes

If we didn't identify any peculiarities for other processes, that's simply because there aren't any specific issues the user of a standard AM process is not already aware of. As these materials are usually the same but used at a larger scale, the main problems that require specific attention are usually seen at the design and/or printing process levels.

To that, Autodesk's Ferguson warns that *"there is a trend toward larger-format powder bed machines, which requires greater care during the build preparation, toolpathing, and simulation stages because as printed parts get larger, the cost of failure dramatically increases. Predicting potential issues before starting the print, a specialization of Autodesk Netfabb, is of tremendous value". "Netfabb also allows for the simulation of DED toolpaths for thermal and mechanical analysis. This enables users to look at the internal temperature of the whole model as it is being printed, and aid in deciding when to add breaks in the toolpath for cooling. It even can predict what the final distorted shape might look like,"* he adds.

That said, Fusion 360 has other tools that can aid in LF-AM as well, for plastics and other materials that can have complex infill patterns. The software provider recently introduced **Volumetric Latticing**, a tool that enables users to create infill structures that can provide strength while using less material, meeting this way cost, weight, and/or sustainability requirements.

Legend: An analog moon habitat which was designed, constructed and installed in 9 months. Ingersoll's technology has been used at the manufacturing level.

Legend: For this MOnACO project – a clean aviation experiment – the number of parts in an assembly has been reduced from more than 100 down to a single part. (Fusion 360 generative design was used in the structural and fluid flow design optimization for this project).

The common pitfalls of large-scale additive manufacturing and other cost considerations

Just like AM in general has led many industrials to have a misleading appreciation of the technology, LFAM processes may often induce disguised expectations for those who are not familiar with the different technologies.

Based on insights shared by **Ferguson, Calvert** and **Andy R. Bridge**, we can already point out the pitfalls below:

- LFAM doesn't replace existing AM processes; it complements them. For large parts, this is not replacing other forms of AM; it is replacing hand-crafting the parts from scratch or traditional subtractive processes.

- Since most LFAM processes have a robotic feature, people often think there are plug-and-play systems. The operators always need to be well-trained. The more processes will be automated, the quicker the training process will get.

- Bigger prints and more material mean it's expensive to have a print failure. Process test prints to fully understand your process, try to know your problems before you have them. Determine if any bad sections can be cut out and/or repaired.

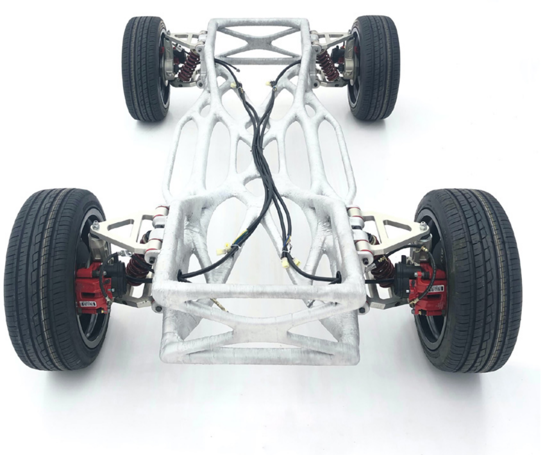
- Most LF-AM machines bigger than about 1m x 1m x 1m are not mass-produced machines. Instead, they're typically custom systems or in their early years, so they can be tricky to operate, requiring bespoke software.

- Not knowing a process well enough could be seen as a pitfall, costing more (waste), introducing stress concentration points, under-printing or over-printing, etc. Material flow rate out of a nozzle, for example, adds its own difficulty and isn't specific to one process. In a lot of cases, it is simply not an option to pause or change the extrusion speed on the fly, or it's very wasteful to do so.

It's worth keeping this in mind:

- in addition to the capital costs for the Large Format printing equipment, there are many other areas of cost to consider. Some of these are software, polymer expertise, design expertise, process control, engineering investment, and training. Certain end-use products like aerospace tooling also require large-scale precision CNC mills.

- Last but not least, sometimes, it's not about costs, it's about lead times.



To date, **industrialization is still a goal to achieve for those who explore the use of LFAM technologies.** Use cases already developed with the processes range from prototypes to small series productions across applications within the **aerospace, marine and construction industries.**

What we find the most interesting is that there is momentum in the construction industry –where there is a need to reduce man-hours – and applications in this field reveal that concrete 3D printing is not always the only production candidate that can be used to achieve that.

A few words on the contributing companies

Additive Engineering Solutions (AES) is an advanced manufacturing company that provides large format polymer additive manufacturing (LFAM) solutions. Whether it's 3D printing large tools and molds for the composite aerospace & defence industry or printing large end-use parts for the AUV markets; AES ambitions to demonstrate the ability to manufacture a variety of products with more efficiency and customization than traditional methods. The company is looking to explore vitrimer materials in the near future for LFAM applications.

Autodesk is a software company that provides several solutions that can assist in LFAM, ranging from simple 2.5D slicing to multi-axis, non-planar slicing, the ability to drive desktop machines, hybrid machines, and robots, and the ability to simulate metal prints in order to detect possible issues before getting on the machine. Autodesk offers software that covers most of the additive space, including LFAM. One issue seen across industries is the idea that data is separate, usually programming in a separate software from the design. For additive, especially LFAM, having to switch back and forth from separate design and programming packages for design changes means a lot of exporting and importing. The company's software solutions are designed to eliminate this issue, enabling a more seamless workflow.

Ingersoll builds large polymer 3D printers and automated fiber placement machines. The company's portfolio comprises gantry-style printers and robotic 3D printers. All machines are hybrid and can be equipped with printing, milling, automated fiber placement (AFP), or ATL (automated tape laying). Ingersoll also provides contact printing services for aerospace tooling, the marine industry, or life-size furniture applications.

AMSC 2023

The International Catalogue of AM Solutions

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

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

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

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

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

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A closer look at Robotic 3D printing – what really slows down the adoption at scale

If you want to manufacture parts that measure up to 30 meters in a single printing operation; if you want this production to be automated and accurately repeated, there is a great chance that robotic 3D printing is your ideal production candidate. On paper, such a combination of robotics and 3D printing is what most industries picture as the ideal move towards smart manufacturing. In practice, there are some hidden constraints that prevent a large adoption of this form of manufacturing.

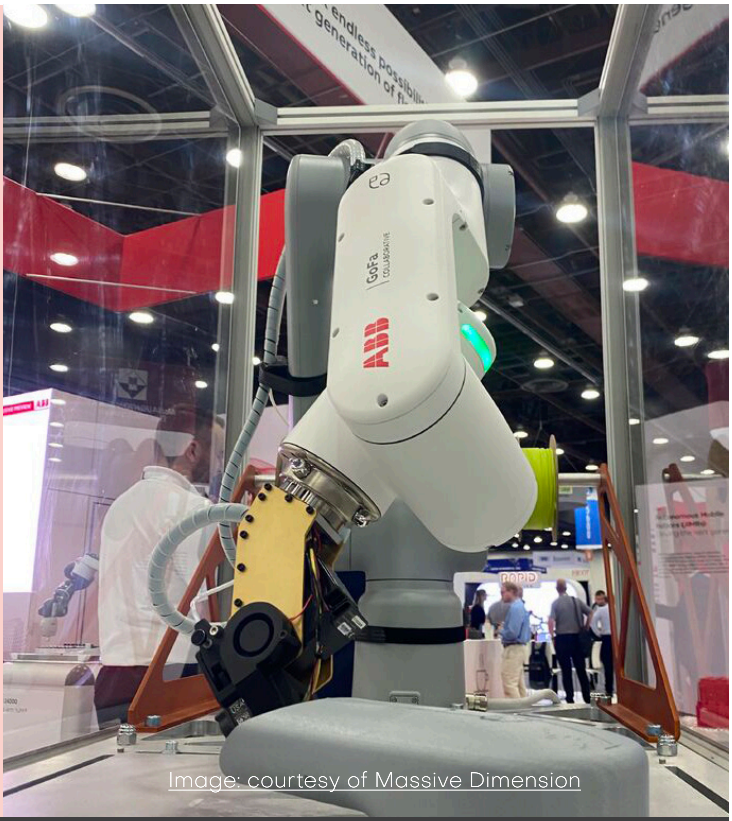


Image: courtesy of Massive Dimension

When talking about robotic 3D printing, it might be easy to get carried away by robotic solutions that are increasingly being developed across industries to support or replace human tasks. Please, note that this article is in no way related to that. However, if you are looking to learn more about the combination of robotics and 3D printing used in the manufacturing of parts, then stay with us.

Image: courtesy of Massive Dimension

Robotics and 3D printing can be combined in two main ways.

One of the most widely used techniques consists in combining a 3D printer head that extrudes materials with a multi-axis robotic arm. This technique provides a level of freedom that "conventional 3D printers" do not usually provide. This is often the most widely used technique as it is directly linked to manufacturing per se. This form of manufacturing – which constitutes the focus of this article – is referred to as Robotic arm 3D printing, robotic additive manufacturing (or simply "RAM") and can be integrated into different types of AM technologies (FDM, metals, ceramics, concrete, etc.). Confusion should not be made with a gantry system for 3D printing. (A gantry system moves in three axes whereas a robotic arm moves in six axes).

"There are many different types of end-of-arm tooling for robots for a 3D printing application. [They] range from thermoplastic, metal injection molding, ceramic to concrete systems [and more]. [They can be] optimized and built specifically for additive and robotic printing applications," **Tyler McNaney**, Founder and Managing Director at Massive Dimension explains.

"Robots are very customizable and versatile. A single robot could be placed on a static pedestal and the print might move, or the robot could be made movable and the part is stationary. Both of these could change the DFAM, depending on the process. Let's take for instance the buckling that can happen when printing a large part vertically: it may be necessary to create buckling

mitigating features on the part. If the part has the ability to be printed on its side or upside down, then the physics of gravity on the part may impact the need for, or design of, these features.

Furthermore, robots can very easily be configured with multiple end effectors, thus it is very easy to repurpose a robot. This means someone who starts with a wire arc end effector can keep the same robot and change to a laser powder process. Imagine doing that with a powder-bed machine!

This also allows us to look toward multiple dissimilar materials being printed on one cell, like a plastic or elastomer on a metal – things that might normally be done with a plastic injection process.

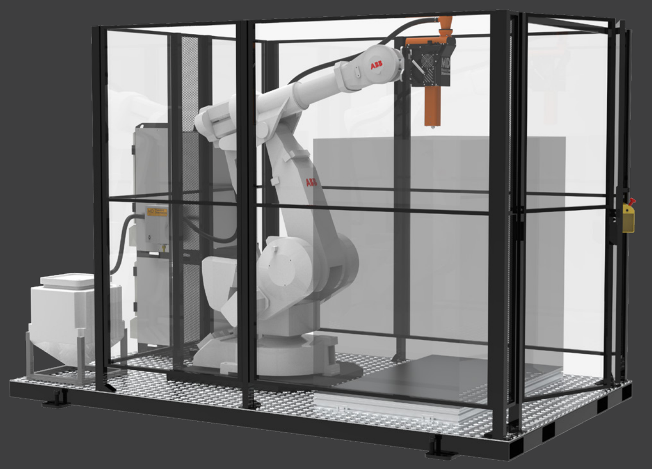
Robots are not as precise as what we've come to see as the standard for AM, powder bed machines or SLA machines. Recognizing this inaccuracy at the design level, and that post-print processing will be required, is necessary," **Justin Ferguson**, Autodesk, Senior Solutions Engineer adds.

On another note, 3D printing and robotics can also complete each other when one is looking to establish an integrated solution throughout the manufacturing process. In such cases, an industrial robot could replace a manual step of the manufacturing process. It could be replacing a 3D printer's build plate or performing the washing, curing and final finishing steps in post-processing with robotic arms.

"A robotic additive printing solution is very flexible in terms of customization; the initial printing setup can be customized beyond what it was originally designed to produce. For example, a robotic printer could have one work volume on a fixed surface, in another location, a rotary positioner could be added, and furthermore, additional build areas can be installed for specific part build requirements. Within the printing process various deposition tools can be added to the end of the robotic arm, as well as post-processing tools such as mills, sanders, or other finishing tools," **McNaney** outlines.

A double-edged sword

As mentioned above, the **need to manufacture large-scale parts** is often the first argument that plays to the strengths of RAM. RAM also amplifies **the freedom of creating complex shapes** that AM already enables. The reason for this is quite simple: with their articulated joints, robotic arms can easily move along and around multiple axes. In the same vein, a robotic print bed that can rotate also gives room for more freedom. This enables **the manufacturing of parts without support structures and a reduction in materials usage**. Those support structures can even be completely avoided when the build platform moves, enabling this way the model to be reoriented.



Here is the thing, these advantages can be a double-edged sword as with so many moving parts, the machine would need detailed computer instructions to meet the manufacturing requirements. Indeed, improper planning and control can influence the printing quality or can lead to the arm hitting the printed part, causing damage. Not to mention that the robot's motion control systems can also influence the part quality or effectiveness of the printing process.

"Where a conventional XYZ printer can only build up, a robotic movement system can reach down after building an object; robot system can be quickly adapted for a range of printing methods such as non-planar, multiplanar, and angled printing," McNaney points out before warning on the design considerations that should be taken into account: *"features should be designed within the nozzle diameter size and should not exceed the capabilities of the printer or materials just as like desktop printing."*

To date, there are no recognized standards for the transfer of information between the CAD system and the arm, which leads many machine manufacturers to create their own workflow to simplify the manufacturing process with a robotic programming software solution.

That said, one will never emphasize enough **the importance of the 3D software solution** used as part of the manufacturing process. The movement of the robotic arm and therefore the distribution of the material depends on this software solution. The ideal 3D software should be able to accurately model the developing part as it is built, to ensure that the robotic arm does not collide with the build as it grows and to prevent potential shrinkage issues that may occur during the printing process.

Applications and current market

Boats, car bumpers, large molds, fixtures, and any object in the rotomolding industry can be produced with robotic 3D printing.

From the technology standpoint, the market isn't exactly overflowing with hundreds of 3D printer manufacturers, given the specialized nature of robot-assisted 3D printing. The robotic AM market features an exhaustive list of companies that provide **robotic 3D printing software, end-of-arm printheads and extruders, robotic arms and robotic 3D printers.**

The table below provides a few names that you may find in this market – it does not take into account companies that provide robotic 3D printing services:

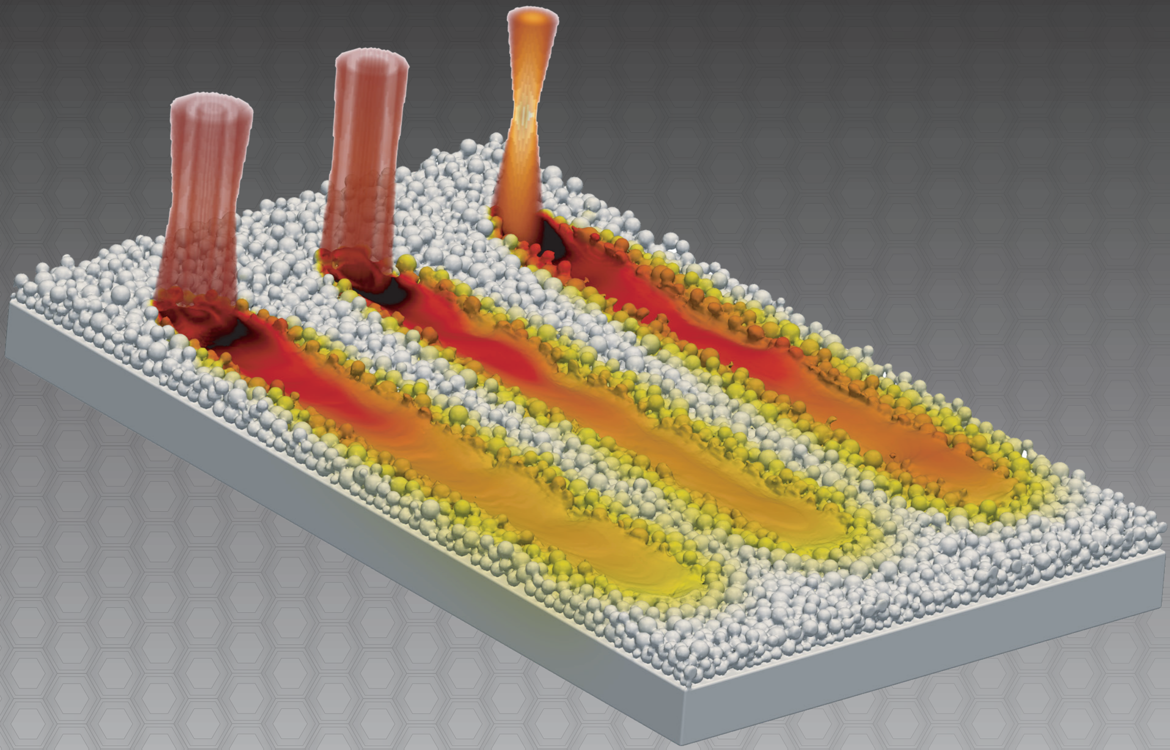
Robotic 3D printing software	End-of-arm printheads and extruders	Robotic arms	Robotic 3D printers
ADAXIS	Weber Additive	Comau	CEAD AM Flexbot
AiBuild	Massive Dimension	ABB	MX3D M1
Robotmaster	Dyze Design	Stäubli	Caracol
Octopuz OLRP	Rev3rd	KUKA	Continuous Composites
RoboDK	Bloom Robotics	Vertico (for concrete)	Orbital Composites
		Twente AM (for concrete)	
		Hyperion Robotics (for the construction industry)	

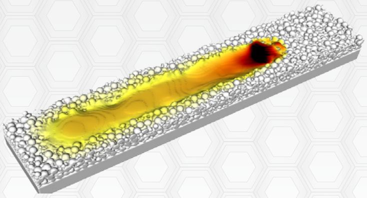
On a commercial standpoint, leveraging an in-house robotic 3D printing solution requires a strong business case. Indeed, in addition to the related equipment that a standard AM process may require, a customized robotic 3D printing solution may require a robotic arm, a robotic 3D printing software solution if it is not already integrated into the printing solution, and the printhead. Most of the times, these solutions do not always come from the same provider and this makes the overall cost of investment quite expensive.

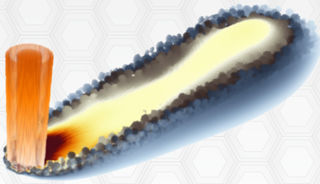
This raises some complexities with the integration of certain platforms and the adoption of robotic 3D printing solutions at scale – all of which can be addressed through collaborations between the main technology providers.

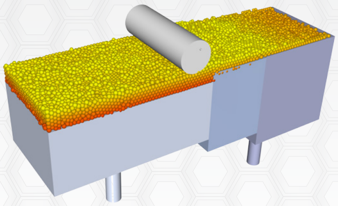
Key contributor

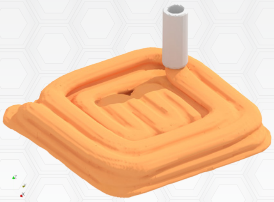
Massive Dimension is an OEM for robotic additive 3D printing printer cells. Between Filabot and Massive Dimension, the company has over 11 years of experience working in the additive market. From the ground up, they produce their extruder systems, build out cells, and provide these products on a global stage. They are an ABB Valve Provider where they have access to all the resources needed to successfully install and commission robotic cells from the ABB robot product line. They also have universal robotic compatibility options turning any robot into a large format 3D printing machine.











Thermwood gives hope for the future of recycling, demonstrates superior printed part quality with "Thermal Sensor Layer Automation"

This year's Rapid + TCT conference in Chicago featured a range of machines and parts, from huge robotic AM machines to the nearly microscopic printed metal pieces used for hearing aids. However, one installation towered above the rest. ***Thermwood*** *was there showing off their LSAM AP510 machine.*

If you're a regular reader of 3D ADEPT Media, you are certainly familiar with Thermwood. The machine manufacturer made Large-Scale Additive Manufacturing (LSAM) its core business as they wanted to provide an alternative to the widely spread polymer 3D printing approach. Their portfolio starts with the AP510 at a bed size of 5' by 10', and goes up to the LSAM 1540 that prints on an expansive 15' by 40' platform. For readers in the US, that's about the length of a school bus. As explained in a recent article, this approach was hard to scale up, for large near-net-shape parts, hence the focus on the development of dedicated systems.

Our conversation with Thermwood's Executive Vice President, **Jason Susnajara** gave us the opportunity to confirm how the company headquartered in Indiana, is walking the talk on a number of topics we have been discussing for the past several years.

For the record, Thermwood has been showcasing its LSAM expertise on various European and American trade shows. Among the wide range of shows where we've had the opportunity to meet the company's representatives, Rapid+TCT gave us the chance to appreciate a live demo of the company's technology. As English clergyman Thomas Fuller said: "Seeing is believing, but feeling is truth."

While we were talking with Jason Susnajara, an orange behemoth worked away at printing a green plastic chair.

Hope for the future of recycling

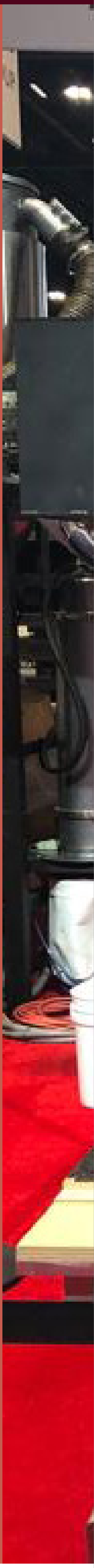
According to **Susnajara**, the opportunities for large-scale 3D printing lie in the fact that manufacturers can save on labor and material costs. Thermwood was showing off the AP510's sustainability side by 3D printing the chair with polymer pellets made from recycled plastic bottles.

Remember when we discussed the arguments that would play to the strengths of LSAM when it comes to sustainability? Recycled materials were the second argument mentioned in the "environmental category" to help organizations embrace a sustainability journey. We knew Thermwood's LSAM machines could process recycled composite chopped fiber-reinforced polymer (FRP) pellet materials, thus improving material efficiency and reducing material waste. At Rapid+TCT, we got the chance to learn more about one of these materials.

The AP510 3D printer was processing an **LNP™ ELCRIN™ WF0061BiQ material,** developed by **SABIC**, a specialty chemicals company that is also active in the AM industry. The material comes from PET water bottles that SABIC transformed into polybutylene terephthalate (PBT) resin to create polymers with new properties compatible for AM. The newly-developed material delivers the same strength and quality as the virgin PBT resin.

We didn't ask if these materials could be used to achieve industrial LSAM applications. We believe they can, given the strength of the chairs printed and the properties of the material processed. Nevertheless, we do hope to continue this conversation on other focal points that could help demonstrate how the triple bottom line is met at the manufacturing level.

During the live demonstration, a **sort of camera** was monitoring the printing process as it was taking place. With the camera, one could see how the temperature of a printed layer was measured just before a new bead is added which enabled the printer to automatically regulate the feed speed. According to **Susnajara**, the idea is to find the perfect balance between cold and heat in order to have the desired shape. With this layer time option, one can go slow enough so that the printing process would be at, or very close to, the perfect temperature needed to achieve the best possible layer-to-layer fusion. From what we saw, the machine was printing **200 pounds/hour (90Kg of pellet materials/hour).**



The AP510 had an imposing presence on the exhibition floor at Rapid + TCT. Susnajara said they were printing four chairs throughout the three-day show. Onlookers would stop and tilt their heads upward to take in the whole machine. The chairs we saw at Rapid+TCT were strong, and so heavy (around 40 pounds ≈ 20kg) they look unbreakable. After the show, they would go back to Sabic's plant.

Thermwood AP510 printing a chair on the floor at Rapid+TCT. Photo courtesy of 3D ADEPT Media.

Industrial applications enabled by Thermwood's LSAM

As far as the market for these printers goes, Susnajara said Thermwood's LSAM machines are being used for applications like **autoclave molds**. Such components usually require a rigid mold that defines the final shape of the composite part, in order to manufacture an end-use part that must deliver high-performance properties and withstand austere environments. As a reminder, Thermwood previously shared how it manufactured an autoclave tooling of 1150mm x 760mm using SABIC's LNP™ THERMOCOMP™ AM EC004XXAR1 compound, a 20 percent carbon fiber-filled ULTEM™ resin material. The printing process of this tool required eight hours and they required 12 more hours for machining using the LSAM® printer.

Other industrial applications from Thermwood that are worth recalling – and that have been publicly shared, include Meander, a large sculpture that highlights Missouri River's footprint in KANSAS, the massive 3D printed torch in the new Las Vegas stadium or a Yacht Hull Mold. These applications demonstrate that with a little imagination and some creative engineering, large structures can be made, even on the smallest of Thermwood's additive manufacturing systems.

LSAM composite for tooling continues to be evaluated to ensure the industrial base can handle future manufacturing surge requirements. Given the milestones and applications it has already achieved ever since it debuted on the market, Thermwood remains one to watch in this industry.

What's Electroplating and when should we use it for 3D printed parts ?

SAMPE Strength Comparison of Topology Optimized Lattice From Printed SLA Resin, Electroplated Resin and PBF Al – Courtesy of RePliForm Inc.

*Like a wide range of post-processing tasks used for 3D printed parts, **electroplating** aims to enhance the physical properties of the part through increased wear resistance, corrosion protection or aesthetic appeal, as well as increased thickness. Here is the thing, very few people in the industry know exactly what the process is, how it works and how it can be applied to AM parts. Unlocking the mystery around this concept is what this article ambitions to achieve.*

Also known as electrodeposition or electrochemical deposition, electroplating is an electrochemical surface coating process that uses an electric current to reduce dissolved metal cations on an electrode surface, called a cathode, forming a thin coherent metal coating. In other words, through this process, one can reduce metal ions onto the surface of a conductive part to apply a metal coating.

There are quite a few metals that can be electroplated but some of the most commonly used are **copper, nickel, chrome, tin, lead, zinc, brass** (an alloy of Cu and Zn), **gold, silver and platinum**. Put simply, this process aims to serve two main purposes: **decorative** and **functional**.

For instance, decorative electroplating is often seen in the automotive industry, where a decorative chrome coating can be recognized on plastic elements such as grilles, bumpers, wheel rims or door handles. One can also use decorative plating for the deposition of precious metals (for instance, gold and silver) on luxury items, and here you might think of watches, or jewelry in general. Furthermore, most people use electroplating to make their plastic parts attractive like polished metal pieces.

The functional electroplating process aims at achieving a metal coating that will, among other properties, prevent the target substrate materials from corrosion. In the aircraft industry for example, where common metals to be plated are cadmium, hard chrome, zinc, zinc-nickel, platinum, tin-zinc, etc., a few examples of parts that can be electroplated include landing gears, engine turbines, or bearings.

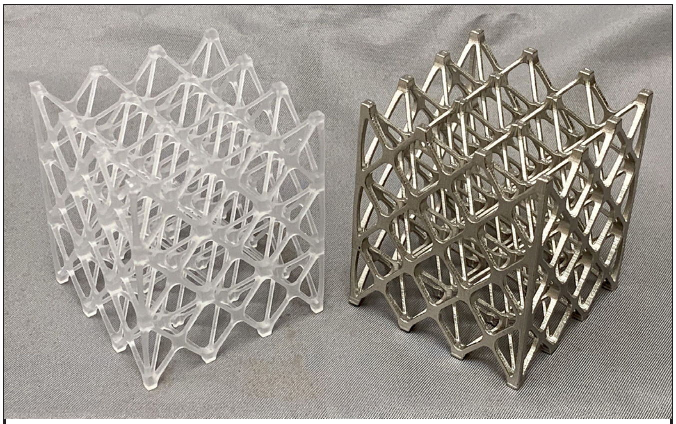
This functional purpose can also involve several other goals: the need for increasing temperature capability of the print, EMI shielding, improved mechanical properties (stiffness and strength), better durability, barrier coating to stop outgassing (i.e. a vacuum environment) or prevent an attack of chemicals on printed resins substrates. It can also reduce flammability and toxic fumes from combustion. This means that a 3D-printed part that underwent electroplating can also serve as a replacement part for a given component that had a specific function in an assembly.

In the post-processing of 3D printed parts, **electroplating is just one way of surface finishing like 3D printing is just one manufacturing tool.** To successfully obtain a metal coating on a 3D printed part by the electroplating process, one needs to recognize what type of substrate material we deal with, whether this is a plastic part, or a metal-based part, and the function of the deposited metal layer, decorative or functional, and we are ready to go.

With what 3D printing technology can we use electroplating ?

In general, the 3D printing process used for part manufacturing does not really impact the electroplating task. However, one tends to realize that **photopolymer, fused/sintered powder or filament** 3D printed parts can be plated. The easiest process to plate is photopolymer, but the parts need to be cleaned and well cured. The complexity with fused/sintered parts is that they can have a bit of porosity and the surfaces can be rough. Most 3D printers can be set up to make the outer skin of the part watertight but there can be some variability in batches. The surface roughness can improve adhesion but it's more difficult to get a high gloss finish with these. FDM remains the most difficult process when it comes to electroplating because there is almost always porosity in the part and the pore sizes in certain regions of the parts can be quite large. Parts need to be sealed prior to plating which adds to the cost to process these.

That being said, regardless of the AM process used for the manufacture of 3D printed parts, what really matters are **the substrate material this part is made of and its geometry:** metallic parts barely raise issues compared to plastic parts that require the operator to ensure that the material used for the manufacturing, can withstand the chemical bath that will be used for the electroplating process.



SAMPE Strength Comparison of Topology Optimized Lattice From Printed SLA Resin, Electroplated Resin and PBF Al – Courtesy of RePliForm Inc.

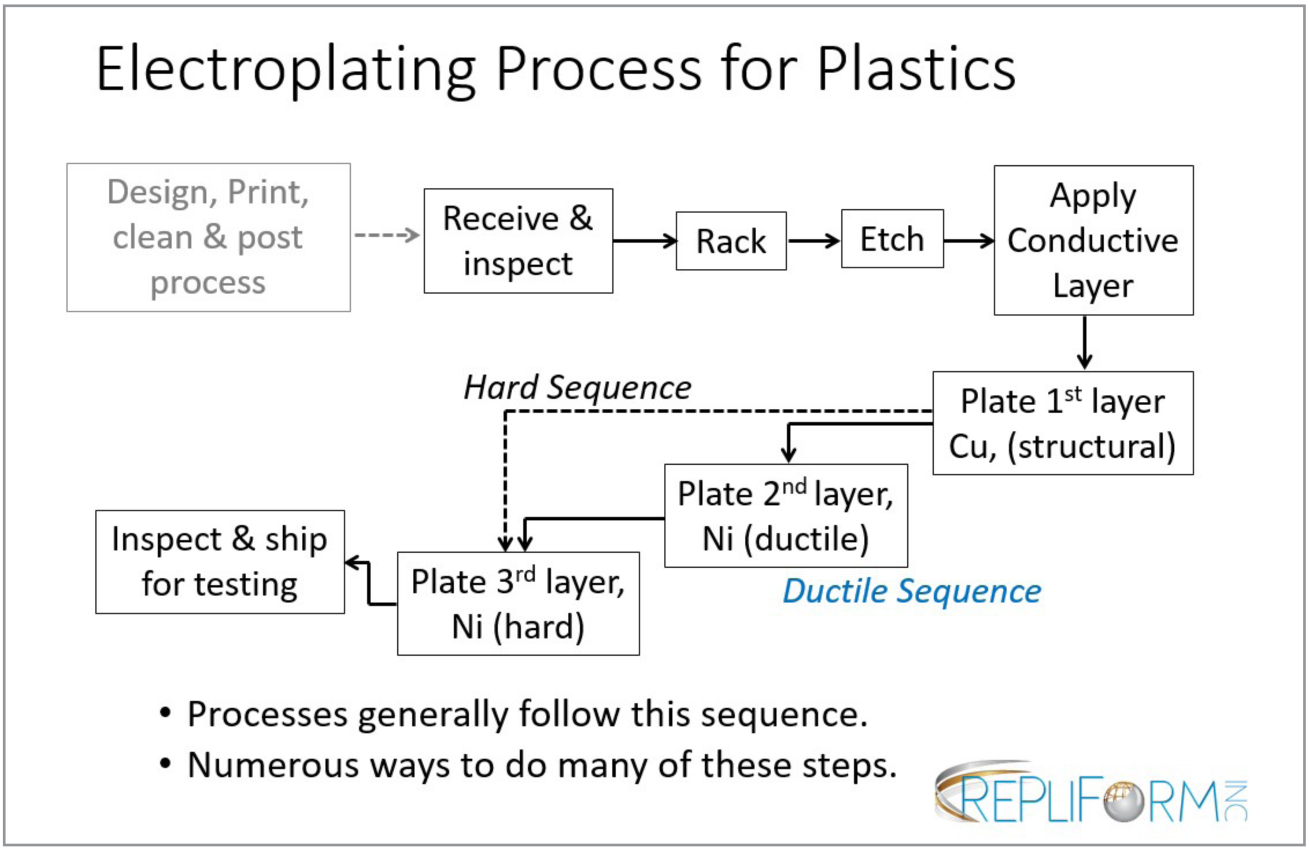
Furthermore, the more complex the geometry of the part, the greater the non-uniformity of the deposited metal on its surface. This makes the electroplating process challenging for process control, and achieving an even metal layer coating distribution over all active surfaces to be plated might not be possible without developing dedicated mitigation strategies.

Since 3D printed parts are usually complex, it is often recommended to use **a computer-aided engineering approach** in electroplating. Such an approach aims to ensure upfront process analysis towards recognition of under- and over-plated surface areas. This way, one could predict the metal layer thickness distribution over a printed part before the actual electroplating process will be run. This, in turn, gives the operator the possibility to optimize the process setting and make sure the part is plated right first time and in compliance with the required metal layer thickness specifications.

How to apply electroplating on 3D printed parts?

Plating onto 3D printed parts is rather similar to the electroplating processes done for typical plastic or metallic parts. One needs to start with uncontaminated parts, then etch the surface, apply a conductive layer with autocatalytic nickel or copper, then apply plating sequence to achieve desired functionality.

Moreover, for plastic 3D printed parts, it's important to make sure that the part is metalized beforehand so that the surface can conduct the current. As shown in the image above, this metalization step is usually done with an electroless deposition and after the proper surface preparation, composed of **a number of pre-processing steps**: cleaning, pre-dipping, etching, neutralizing, pre-activating, activating, and accelerating. Once the surface pre-processing is done, one can proceed with the electroplating step.



Electroplating Process for Plastics

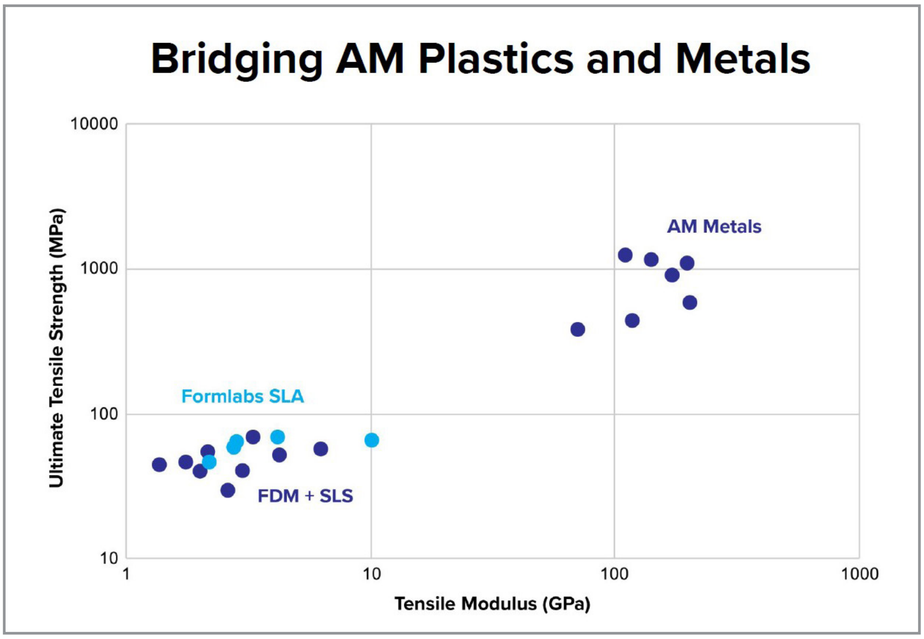
- Processes generally follow this sequence.
- Numerous ways to do many of these steps.

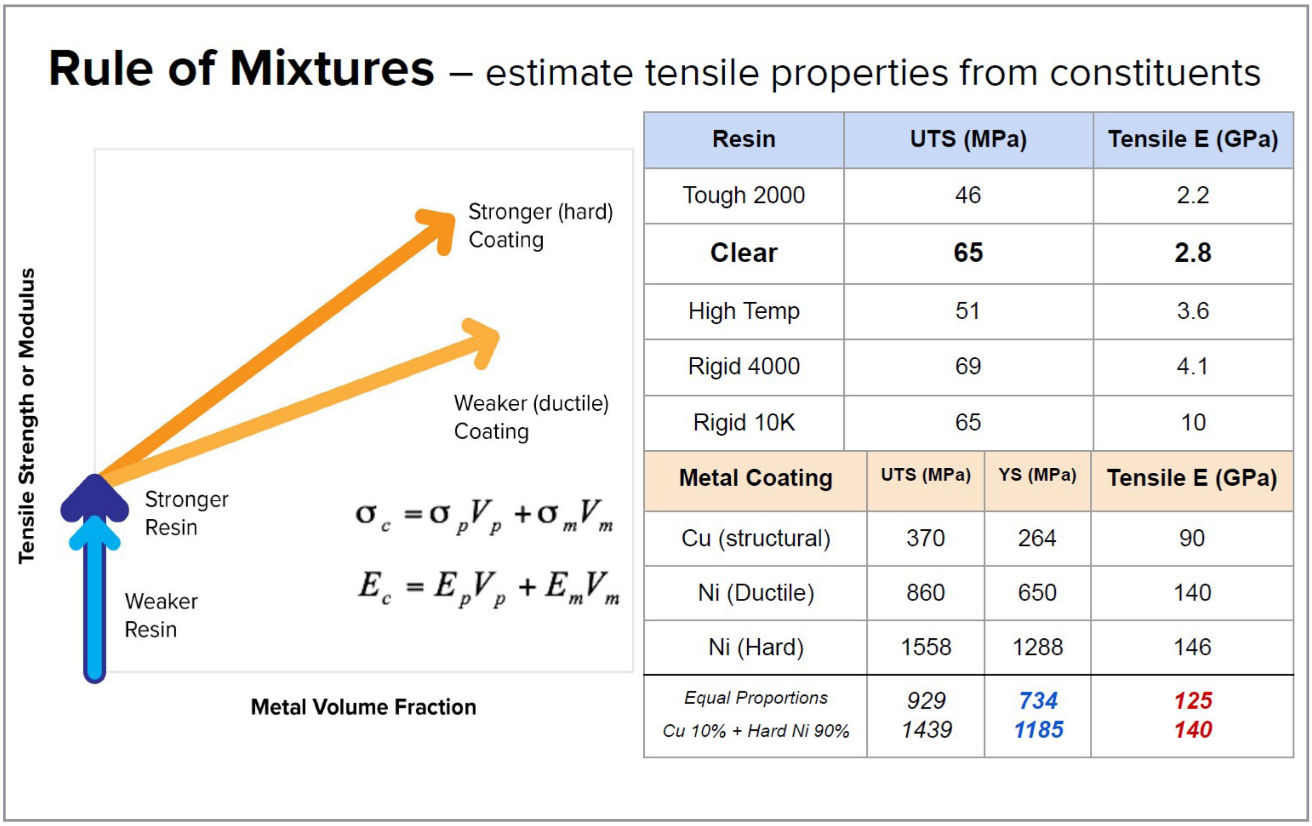
Determining how electroplating alters mechanical properties of 3D printed parts

On another note, determining how electroplating alters the mechanical properties of 3D printed parts requires developing an understanding of several mechanics. Electroplating on 3D printed plastics, for instance, can make a reinforced composite and add metal functionality to non-conductive metals. To create a metal-resin composite from SLA and electroplating for instance, one should determine if a plated plastic can fill a gap between printed metal and plastics, one should understand the rule of mixtures to estimate tensile properties from constituents or learn to make room for the coating when you already have the design.

To understand this type of mechanics and many others, companies like **RePliForm Inc.** work with many systems suppliers and resin manufacturers to test tensile and flexural strength. Indeed, as the properties of the resin change, the properties of the coating change as well, and this influences the way the part design changes.

That being said, as far as the creation of a metal-resin composite is concerned, it turns out that treating the plated part as a composite and using the rule of mixtures – a very basic equation used to estimate the strength of composite parts – works surprisingly well.





Rule of Mixtures – estimate tensile properties from constituents

$$\sigma_c = \sigma_p V_p + \sigma_m V_m$$

$$E_c = E_p V_p + E_m V_m$$

Resin	UTS (MPa)	Tensile E (GPa)
Tough 2000	46	2.2
Clear	**65**	**2.8**
High Temp	51	3.6
Rigid 4000	69	4.1
Rigid 10K	65	10

Metal Coating	UTS (MPa)	YS (MPa)	Tensile E (GPa)
Cu (structural)	370	264	90
Ni (Ductile)	860	650	140
Ni (Hard)	1558	1288	146
Equal Proportions *Cu 10% + Hard Ni 90%*	*929* *1439*	***734*** ***1185***	***125*** ***140***

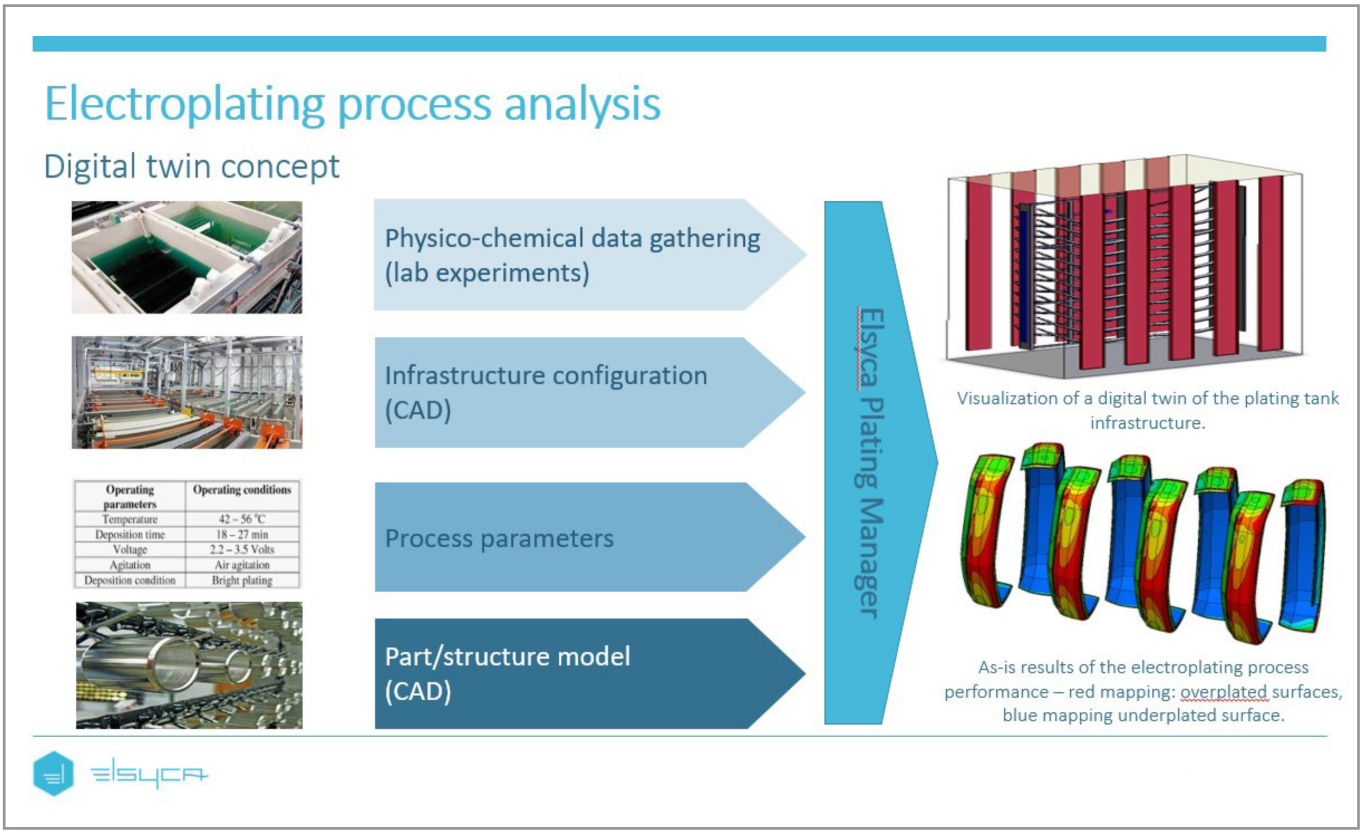
Improving electroplating via a Computer-Aided Engineering approach

Enhancing electroplating via a Computer-Aided Engineering approach is important as we navigate the era of Industry 4.0 and Smart Manufacturing concepts, which 3D printing and digital twin are both parts of.

The approach of a computer-aided engineering relies on the **recognition of the electroplating process performance and its further optimization before any actual wet run will happen.** This can be done by creating a virtual representation (digital twin) of the actual plating process setup in a computer environment. This digital twin is based on the technical information coming from the real-life process site, taking into account plating line infrastructure, operating parameters of the plating process, electrochemical performance of the plating bath used, geometrical characteristics of the component to be plated, and a specific rack layout we have envisioned.

With this approach, one can **predict the current density and metal layer thickness distributions** over all active surface areas that have to be plated, recognizing the surface risk issues in terms of over- and under-plating. Once this knowledge is gained, one designs and evaluates an appropriate mitigation strategy, dedicated to the process setup and to the specifics of the part's geometry. This is extremely important in the case of geometrically complex parts such as 3D printed ones, where neither changing the rack layout nor tuning up the process parameters will allow for an even coating coverage.

For such complex parts, the process setup will need to be improved and a dedicated tooling concept will need to be developed and tested. In real life, assessing the process risks and sorting out a proper mitigation strategy, including testing, takes months and months of hard work and wasted resources. **The approach of computer-aided engineering allows us to do it within a few minutes, eliminating an excess number of wet tests and thus, saving time, money and resources of all kinds.** Using a computer-aided engineering approach we are improving our process knowledge and gaining control over its performance, assuring the best quality possible, each and every time.



Electroplating process analysis

Digital twin concept

Operating parameters	Operating conditions
Temperature	42 – 56 °C
Deposition time	18 – 27 min
Voltage	2.2 – 3.5 Volts
Agitation	Air agitation
Deposition condition	Bright plating

Physico-chemical data gathering (lab experiments)

Infrastructure configuration (CAD)

Process parameters

Part/structure model (CAD)

Elsyca Plating Manager

Visualization of a digital twin of the plating tank infrastructure.

As-is results of the electroplating process performance – red mapping: overplated surfaces, blue mapping underplated surface.

So…?

The process of electroplating is definitely a powerful task in post-processing. Although a CAE approach may help speed up the process, it should be noted that it does not seem to have a popular method to automate the process steps. As seen with depowdering, it will take a lot of collaboration between machine and material manufacturers and electroplating experts to advance the process steps and foster its utilization across industrial 3D printing applications.

Authors

This exclusive feature has been co-written by Sean Wise, President at RePliForm Inc. and **Agnieszka Franczak**, Head of Surface Finishing Division at Elsyca N.V..

RePliForm is an expert in the electroplating of 3D printed plastics as well as other non-conductive materials. With the goal of supporting its customers to create a composite part that can expand the envelope of what is possible with a 3D Printed Plastic, RePliForm continuously adapts electroplating processes to a variety of materials and complex geometries. The company recently developed an unexpected way to make a reinforced composite and add metal functionality to non-conductive materials through electroplating of 3D printed plastics. You may reach out to the company here for further information on the topic: info@RePliFormInc.com.

Elsyca is all about electrochemistry and computer-aided engineering solutions. Electroplating, being one of the electrochemical processes, is one of the company's main interests as it is so broadly used in a variety of applications, across several industries. The team at Elysca develops dedicated software solutions for the electroplating process analysis and optimization and provides computer-aided engineering services for those who face challenges with process control, coating quality and reproducibility. Thus, electroplating of 3D printed parts fits very well in the company's scope of interests. Elysca recently presented how they help industrials take electroplating processes to the next level via a Computer-Aided Engineering approach. You may reach out to the company here for further information on the topic: info@elsyca.com.

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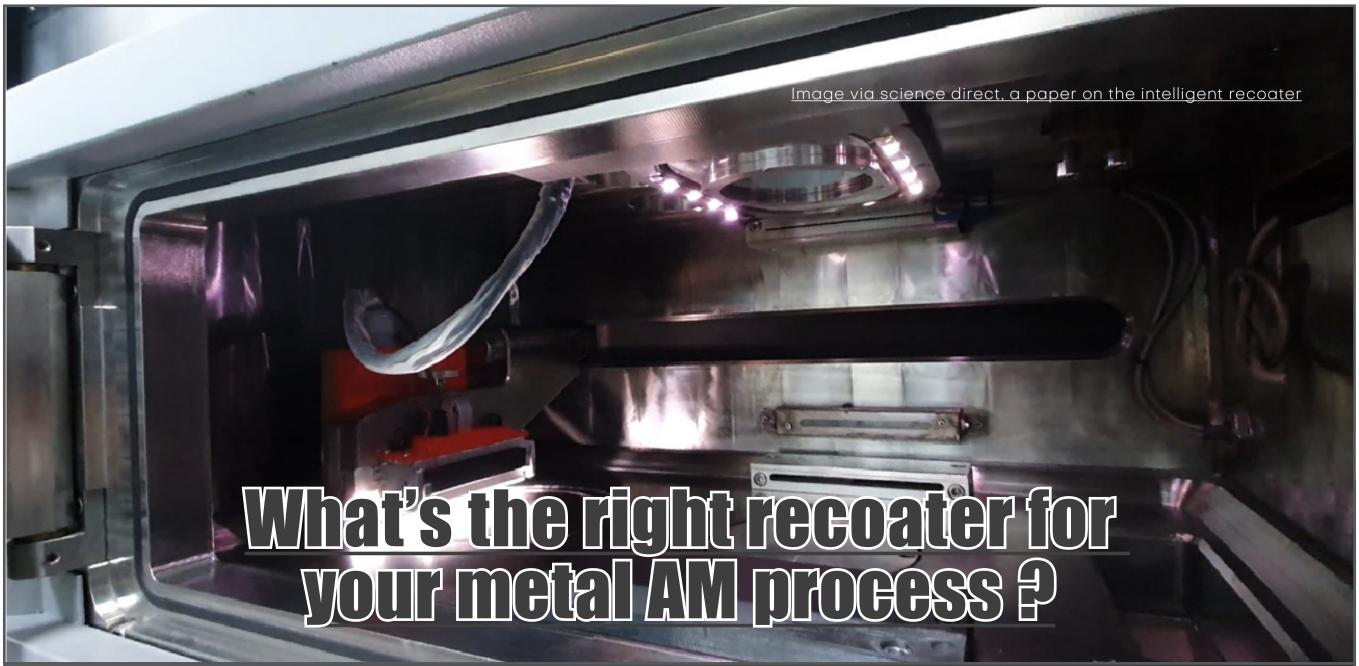


Image via science direct, a paper on the intelligent recoater

What's the right recoater for your metal AM process ?

It might be easy for engineers or designers to think that, because they are not directly involved with the manufacturing of parts, they shouldn't know about certain complexities surrounding the hands-on operation of machines. This is not true. Being aware of the variables and complexities related to the hands-on operation of machines helps to ensure clear communication with operators and most importantly, that design objectives perfectly meet manufacturing expectations. One of these complexities consists in understanding the ***importance of recoaters for metal Additive Manufacturing.***

Put simply, a recoater is a horizontal bar that spreads and smooths material during the manufacturing process, to create a uniform and flat layer before the build material is solidified, sintered, melted, or bonded. As confirmed by **Michael Wohlfart**, AM Expert at EOS and **Thomas Spears**, PhD, Director of AAMT, there is a general understanding that only powder-based processes require a recoater.

Nevertheless, research shows that recoaters can also be used in VAT photopolymerization to spread liquid polymer. In such machines, the VAT photopolymerization machine consists of a resin vat, recoater blade, build platform, light source, and control systems. The liquid photopolymer resin is placed in the vat. The recoater is used to distribute and swipe the liquid resin when a layer is cured. The build platform attached to an elevator moves upside down and the part is built on it.

Speaking of examples of AM machines that integrate a recoater, **Thomas Spears**, Director of AAMT, said [they] *"include Electron Beam Melting (such as Arcam) [or] binder jetting (such as ExOne)." "Newer modalities I saw at Rapid+TCT were spreading a ceramic matrix material, photolithography machines like those from 3D Systems, and plastic sintering machines like those from EOS,"* he adds.

That said, this article will focus on the use of recoaters in laser powder bed fusion processes.

The importance of recoaters in laser powder bed fusion processes

In case you are new to AM, keep in mind that laser powder bed fusion processes (short for LPBF) work on a basic principle: the use of either a laser or electron beam to melt and fuse the material powder together. More specifically, a layer, typically 0.1mm thick of material is spread over the build platform. A laser fuses the first layer or first cross-section of the model. A new layer of powder is spread across the previous layer using a recoater or a roller. The process repeats until the entire part is fabricated.

Apart from the fact that it lays the powder down uniformly, a recoater helps control the thickness of the powder layer deposition. The recoating speed plays an important role in this process as it may influence the surface morphology of the powder bed which in turn might jeopardize the manufacturing success of the part and the production's reliability.

The choice of the right recoater, therefore, becomes pivotal as operators may operate their LPBF machines 24/7, with layer changes each minute. That's the reason why, machine manufacturers are increasingly making their recoating process a competitive advantage.

Types of recoater blades

“There are multiple variants of technologies to spread powder in commercial powder-based systems but all of them are referred to as “recoaters”, Michael Wohlfart clarifies from the outset.

Needless to say, peculiarities of some 3D printers may appear as different tools used to spread layers of powder evenly for each layer of a build. “Some manufacturers use a roller to help compact the powder and create a denser and more consistent packing density on the active surface. Velo3D uses a non-contact recoater where they use a vacuum to ensure proper layer thickness,” Spears explains.

One can identify **four main types of recoaters**. According to Wohlfart, there are:

· Hard recoaters: HSS (high speed steel), ceramic blades

· Soft recoaters: Different types of brushes (carbon fiber, metal), different types of polymer blades (silicone, NBR rubber, other types of polymers)

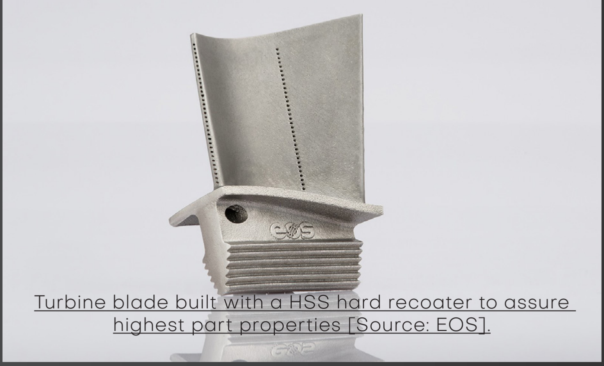
· Roller recoaters: Primarily used in polymer LPBF but also a niche technology in metal LPBF, especially for fine powders that are difficult to spread.

· Contactless recoaters: Niche technology in metal LPBF that allows out-of-plane growth of the application without build interruption but it is typically slow and limited in flexibility (e.g. only one specific layer height). Furthermore, allowing out-of-plane growth is not acceptable for a lot of applications due to tight dimensional tolerances.

As you will realize in the industry, hard recoaters and soft recoaters are often mentioned as the main types of recoaters. That’s the reason why EOS’ AM expert refers to the two others as niche technology.

From our understanding, hard recoaters are a good deal when fabricating identical parts on the same build platform. They often lead to little part deformation. Obviously, if one part in the build deforms, there are great chances that other parts will deform as well.

On another note, if you’re rather fabricating delicate or different parts at once, you might want to choose a soft recoater. It seems obvious, right? In this specific case, if you are handling a batch of different parts, the deformation of one part does not necessarily lead to the deformation of others – therefore, the build will not pause.


Turbine blade built with a HSS hard recoater to assure highest part properties [Source: EOS].

Interestingly, sometimes, these differences are not enough to choose between a hard recoater and a soft recoater.

Some manufacturers will recommend the hard recoater for parts with highest demands given their ability to achieve repeatable quality whereas they will opt for a soft recoater for parts with high aspect ratios and for productions where lead time is more crucial than the risk of imperfections.


Hip cup with different kind of lattice structures built with a HSS recoater [Source: EOS]

While the machines they build are compatible with both hard and soft recoaters, the **Director of AAMT** recognizes that *“there is an element of subjectivity [when it comes to choosing the ideal recoater]. Some users prefer the forgiveness of the soft recoater while others prefer the consistency of the hard recoater despite its stronger likelihood of crashing due to top surface anomalies or part peel-up. Other process considerations can also dictate recoater type as silicone, carbon fiber brushes, and metal rakes are more appropriate for applications where very fine features are required that may be physically destroyed by a hard recoater making even modest contact with it.”*

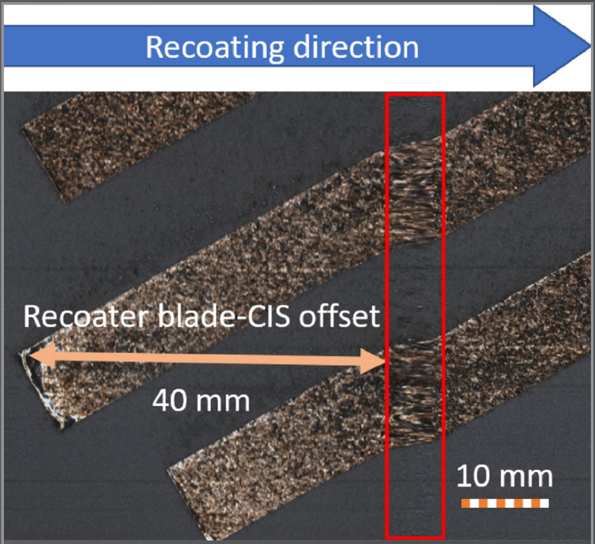
Wohlfart on the other hand, brings further clarification on the topic:

"The processes for metal and polymer LPBF are fundamentally different and there are no machines on the market that could process both materials in the same system. However, there are still differences between the recoater systems than can be explained by the different material/process requirements but also the geometry to be printed may have an influence on the recoater type.

Polymer systems typically use hard recoaters or roller recoaters, because of the elevated temperature of the powder bed and the different nature of the processes. The shape of the hard recoater blade is typically also different compared to metal recoaters because compaction of the powder bed is more essential for the process.

Regarding hard recoaters for metal LPBF systems, a ceramic blade is required if the material is easily magnetizable (for example maraging steels) otherwise, HSS blades are used. While hard recoaters assure the best repeatability in layer height, soft recoaters are recommended for parts with a high aspect ratio."

A couple of tips on part positioning



Legend: Effect of recoater collision on the CIS image. The red box highlights the collision-induced distortion in the CIS image. Image via science direct, a paper on the intelligent recoater

To minimize distortion or failed builds, and to a certain extent, ensure the efficiency of the recoater blade in the long run, the operator should pay attention to part positioning.

In an ideal world, once the recoater has spread a layer of powder, the area of the component built should not move. In practice, depending on many variables, the part could move, leading to a distortion that may apply pressure on the recoater. That pressure could bend or break the component, – or worst scenario, damage the recoater blade.

A correct part positioning may help prevent these issues. For instance, one may avoid having the recoater make simultaneous contact with several 3D printed components at once. The operator can stagger the parts on the build platform to mitigate this risk.

Another example may be to place the tallest parts closest to the recoater. The reason for this is that some 3D printers may require to pause the build, and add powder to build large parts.

On another note, you may not want to place your 3D-printed components directly behind one another. The reason for this is to enable the build to continue if the part or the recoater is damaged.

Last but not least, some part manufacturers increasingly explore the idea of in-situ monitoring of geometric and surface defects in powder bed fusion to monitor the recoating process and prevent issues that may cause a failed build.

A few words on the contributing companies

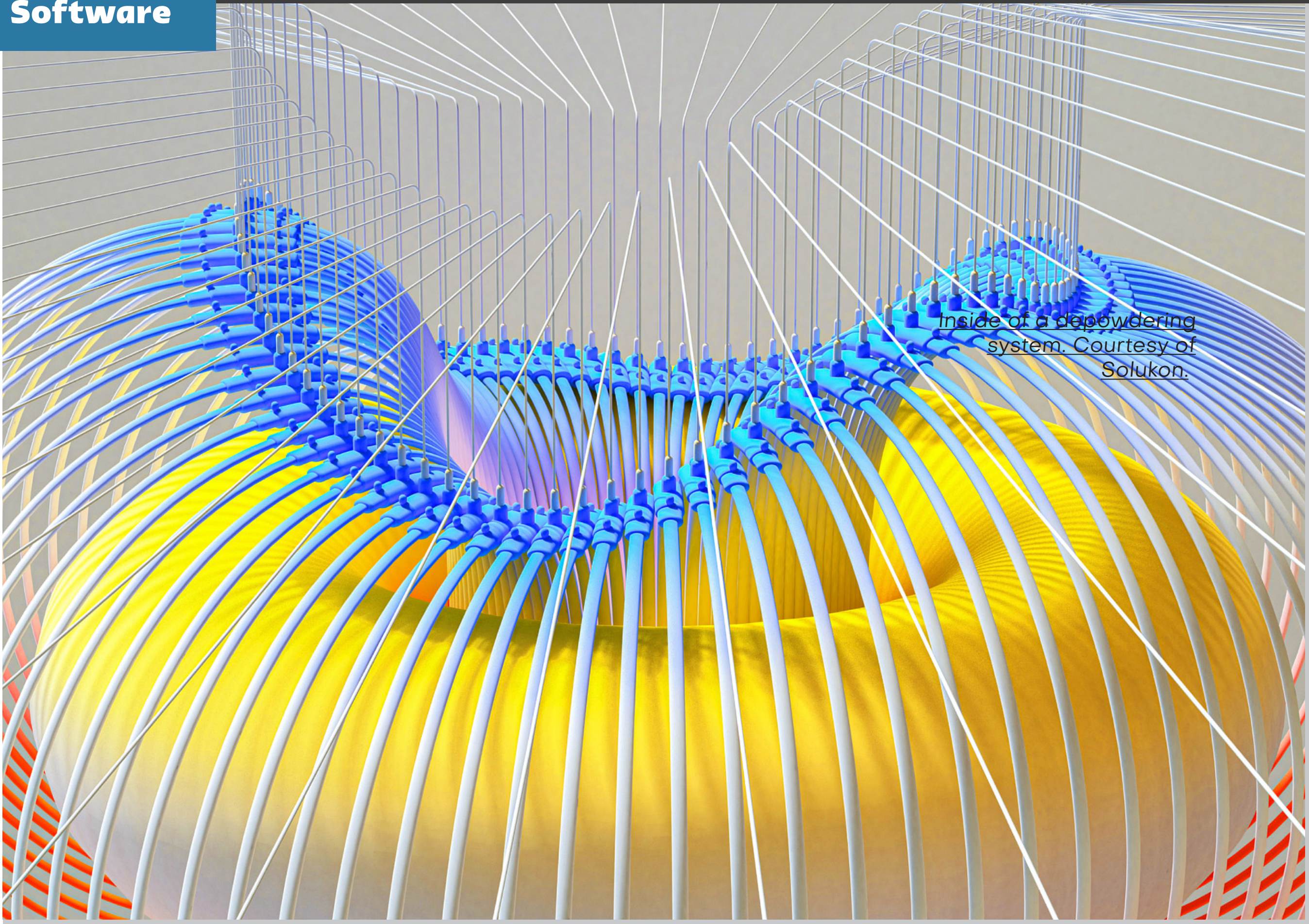
Open Additive is a manufacturer of metal additive manufacturing (AM) systems, process monitoring solutions, and related products and services. The company is part of the Arctos Group, a premiere applied R&D firm that is setting the flight path for the next generation of aerospace and defense technologies. The company has recently released AMSENSE Chimera with Recoat+ to address recoater issues during the manufacturing process. The new **AMSENSE Chimera with Recoat+** offering is specifically designed and tuned to identify recoat process issues common on EOS M400 and M290 machines, providing an affordable 3rd party sensing platform that will increase throughput and decrease build failures on the most critical and widespread LPBF machines in the aerospace market.

EOS is a manufacturing of polymer and metal AM systems. The company provides a wide range of hard and soft recoaters.

Depending on the magnetizability, an HSS (standard) or ceramic blade (magnetizable powders) would be used. While they provide their customers with maximum flexibility and openness, the company said the hard recoater configuration is in most cases the preferred option. Their soft recoater types include:

- Two types of polymer blade recoaters: Silicone and NBR for different temperature ranges and stiffness requirements.
- A carbon fiber brush, which is even more forgiving for fragile and high aspect ratio parts than a polymer blade soft recoater. However, if damage to the brush recoater occurs in case of rising edges or out-of-plane growth due to internal stress, it is also more costly to replace this kind of recoater type.

Based on detailed investigations of different recoater types, the company recommends the right configuration based on their use case.



Inside of a depowdering system. Courtesy of Solukon.

What are the different design tools in the DfAM toolbox ?

A few years ago, to understand how to "rethink design" while taking into account AM technologies' capabilities, we discussed the transition from Design for Manufacturing (DfM) to Design for Additive Manufacturing (DfAM). The dossier we released discussed the real definition of DfAM and shed light on one thing: when performed well, designing for AM can truly increase the value of the part. Fast forward to today, one realizes that the DfAM toolbox continues to be a mystery for many engineers and designers, and one reason that may explain this enigma is the fact that this toolbox is most of the time limited to two principles: Generative Design & Topology Optimization.

The article below aims to serve as an entry point to help designers and engineers understand the different design tools included in the DfAM toolbox, the ones that can enable production and industrialization (strengths and limitations), as well as the ones we should keep on our radar as the field continues to progress. Moving forward, each design tool will be discussed in an in-depth way in dedicated articles.

So, yes, Generative Design (GD) & Topology Optimization (TO) are often the most highlighted design techniques when it comes to designing for AM. According to **Tim W. Simpson**, Professor of Mechanical Engineering and Industrial Engineering, Pennsylvania State University, this can be explained by the fact they "have been around the longest and often show immediate benefits in terms of saving weight and increasing value when using AM." The truth is, since AM is a technology whose history is still in the making, there are many concepts that are not universally standardized – and DfAM is one of them. That's the reason why a thorough understanding of each concept needs a combination of insights from both academia and industry.

In this specific case, we have decided to rely on Tim Simpson's expertise as he has one of the most published academic papers and presentations that focus on DfAM.

According to our expert, other techniques include:

· **Lattice structures**, a way to reduce weight or increase stiffness. This is often referred to as "design for multiscale structures" such as lattice or cellular structures

· **Bio-inspiration**, an approach that is often equated with generative design algorithms, but much broader.

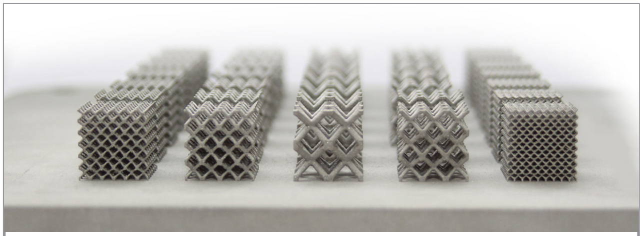
· **Part consolidation or "unitization"**, used to save weight and assembly costs, while increasing the structural integrity of an AM part.

· Conversely, one can also use AM to make intentionally **porous structures**, which offer many benefits when it comes to fluids and thermal management, for example.

· **AI** that enables all sorts of new computational approaches when it comes to DFAM.

"Good old-fashioned "smart" design can also go a long way when it comes to DFAM. We have become so accustomed to designing parts in CAD, that we tend to limit ourselves to what is easy to do in CAD: move in X, Y, Z dimensions, extrude, sweep, revolve, etc. AM frees you from those constraints, which requires freeing your mind from how one often thinks when creating a model in CAD, which often involves subtracting material away from larger geometries that are combined to make complex shapes. In short, designers need to think "inside out" versus "outside in" when using CAD for AM. This is one way to start changing one's mindset for AM, which is really what the generative design and AI do – inspire designers to think differently about how to create unique geometries that can now be made with AM", Prof. Simpson adds.

Apart from these tools, many experts often consider **mass customization** a design technique. If it is not a method per se, we believe it is counted as one because producing a different mold for each demanded product adjustment usually requires a lot of time, but this time is shortened with an easy-to-modify 3D file that enables customization.

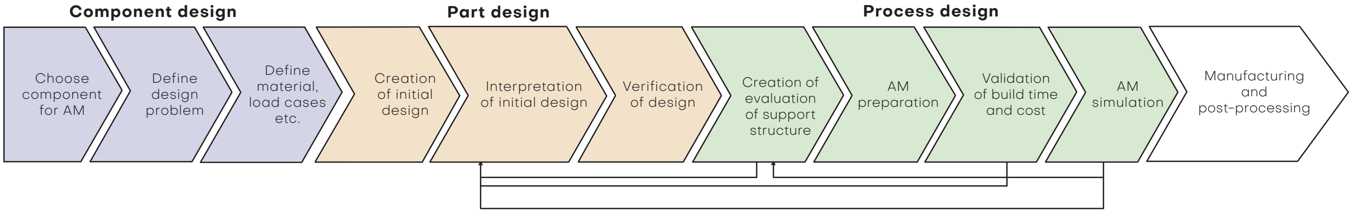


Lattice test structures built on Renishaw AM250 metal AM system at The University of Nottingham, as part of the Aluminium Lightweight Structures via Additive Manufacturing (ALSAM) project.

That being said, whatever method they choose, the designer will always keep in mind the **form, function, aesthetics,** and now, increasingly, **the sustainability** elements of a product design.

Design strategies vs Design techniques

It's pointless to know all these design techniques if you don't know where and how to use each of them. Needless to say, the choice of a design technique, first and foremost, requires a thorough understanding of the design process steps: the component design, the part design and the process design.



To support the decision-making regarding which products or components should be manufactured using AM, research from /a study by **Christoph Klahn**, Head of the Design for New Technologies group at [ETH Product Development Group](), mentions four points **where AM creates possibilities to add value to the product** compared to conventional manufacturing methods.

The first one is **integrated design**, where the focus is on reducing the number of parts in the system. The second is the availability for **individualization of products or components**. The third point is that the manufacturing method enables **a more lightweight design** compared to conventional manufacturing.

The fourth is **the possibility to create more efficient designs**, based on the fact that a more complex part is not more expensive to manufacture than a simple part.

To these items, Klahn adds the **business case perspective** which can be driven by [manufacturing]() (fast production, potential customization, with no need for specific tools or molds – therefore the possibility to change the manufacturing process in other product development stages) or [function]() (take full advantage of the freeform of design offered by AM; may be locked to a specific AM technique and maybe even a specific machine.)

In addition to helping choose the ideal design strategy one may follow for a given application, they also help to decide which design tools one should use. To this, Prof. Tim W. Simpson responds:

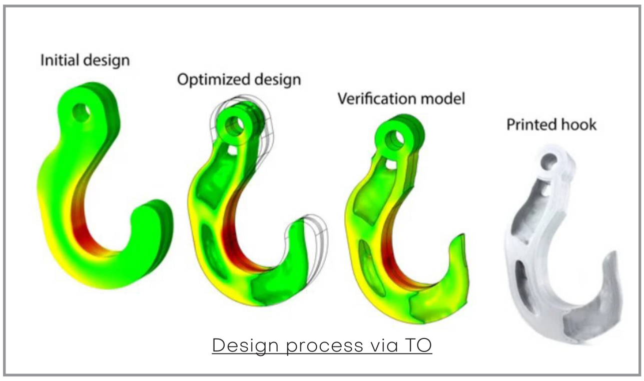
"Unfortunately, the design tools and techniques are often limited—or dictated—by what software is approved for use within a company. There are countless start-ups and cloud-based software tools, for instance, that are now available for DFAM, but they often aren't on the approval list or can't be accessed through a corporate firewall. Students and academics have a lot more flexibility and freedom in what they can use, which may eventually help to transform what DFAM tools and software are used in the industry.

The impact of any design technique is evaluated in terms of how effectively and efficiently *the software can help designers engineer a solution that meets the requirements, which still exist for anything that is being designed, no matter how it is being manufactured. So, finding lighter weight designs, for instance, may be a basis for comparing two solutions, provided all other requirements are satisfied."*

Key specifications of design methods

Let's make something clear: this part of the article does not ambition to say that a specific design technique is better than the other. However, the more one analyzes the manufacturing process of 3D printed parts, the more one realizes that certain advantages can play to the strengths of some design techniques depending on whether they help the 3D printed part deliver an **economic, ecological** or **experience** value.

For example, TO is a technique primarily used for lightweighting the design of structural parts (→ experience/functional value). This means it can help to create one design that's been optimized for structural integrity based on existing criteria, whereas GD can help to create several designs in an evolutionary way.



Design process via TO

"Topology optimization tools certainly have a leg up, given how long these software tools and algorithms have been around. Generative design tools are quickly catching up, and we are seeing a lot more lattice-based designs now given the availability of better software tools to generate complex lattice geometries. AI-based tools are starting to explode around us, and we will certainly see all sorts of novel approaches coming in the next 2-3 years.

At the end of the day, the AM part has to satisfy the requirements and be more cost-effective than any other manufacturing options; otherwise, why would a company want to use AM? Granted, there are many ways for an AM part to be more cost-effective, beyond just a head-to-head comparison of material and manufacturing costs, but this remains central to enabling the production and industrialization of AM parts and products, Prof. **Tim W. Simpson** outlines.

On another note, computational design (which includes parametric design, generative design, and algorithmic design) is increasingly evolving as standards are established within the field. However, keep in mind what **Matthew Shomper** told us in the March/April edition of 3D ADEPT Mag (Software segment | pp -35-36): *"Computational design is a great enabler of complex structures. [...But it is] not for the faint of heart. The tools are rather inaccessible (with large learning curves) and it usually requires a dual knowledge of designing for requirements and aesthetics at the same time."*

Complex design. Courtesy of Matthew Shomper

According to Simpson, the problem here lies in the fact that confidence in the results and the supporting analysis outcomes remain challenging for many companies. For instance, it is very easy to generate complex lattice structures with some of the new software tools, but analyzing the lattices with sufficient accuracy to understand how they may fail in practice increases uncertainty and therefore risk, which can often derail a project. Likewise, differences in the as-printed part from the as-designed part can lead to uncertainty and further increase perceptions of risk when it comes to AM. Finally, a lack of understanding and awareness of what AM is now capable of may lead to resistance to using AM and any computational design tools.

Lastly, any design technique powered by AI will raise a number of questions to date. As we increasingly witness a number of solutions powered by AI, it's fair to say that we are gradually moving from an era of Design for AM to Design for AI. While most designers are still trying to assess the good and the bad of these techniques, the current reality shows that AI can help design an AM part faster and better than a human designer. And for **Prof. Simpson**, *"the real win will be combining the two into hybrid approaches that leverage what humans do well with what AI and computational design algorithms can do well."*

2023

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Materials

Key considerations to take into account for the production of 3D Printable stainless steel powders

There are a number of reasons why one can select stainless steel for additive manufacturing (AM) processes, including its superior corrosion, mechanical properties compared with other steel types (meaning that the component will last longer), and sustainability character. In the article below, Andoni Sanchez-Valverde Erice, Sales/R&D engineer at Outokumpu metallic powder producer, explains some of the key technical considerations in the production of spherical stainless steel powder feedstock.

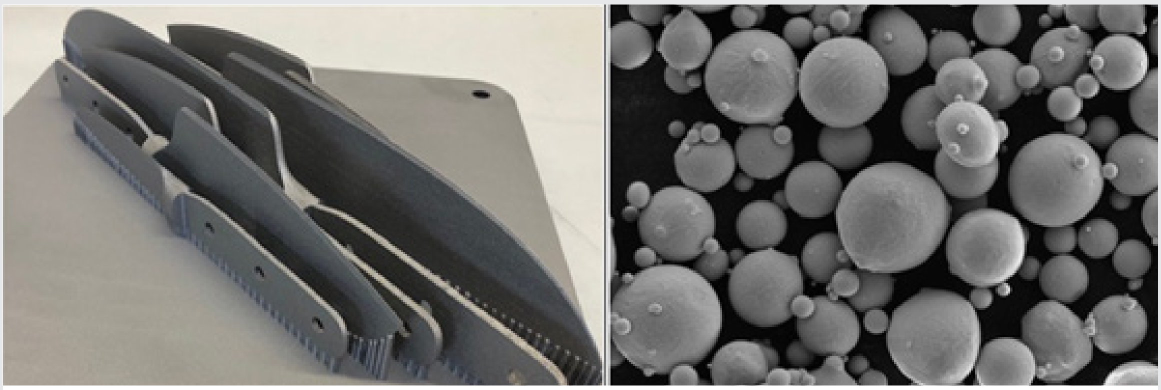


Figure 1 – knives produced by 3D printing (left) using metal power (right) – Knives photograph courtesy of Ernst Krebs KG

Currently, stainless steel is the third most-preferred feedstock for AM industries behind titanium alloys and nickel alloys. However, according to AMPOWER, by the end of 2027 stainless steel will be the most used feedstock with a market share of 33%.

Producing stainless steel powder

Stainless steel powder is produced by the vacuum induction/inert gas atomization (VIGA) process shown in Figure 2. It produces highly spherical metal powders in a range of diameters between 0-300 µm.

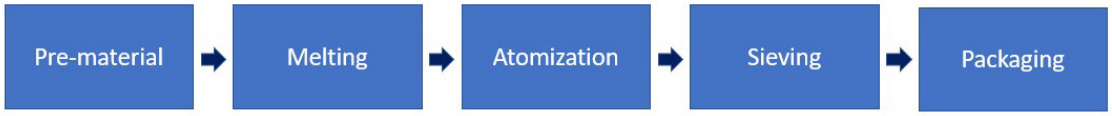


Figure 2 – Schematic of the VIGA process

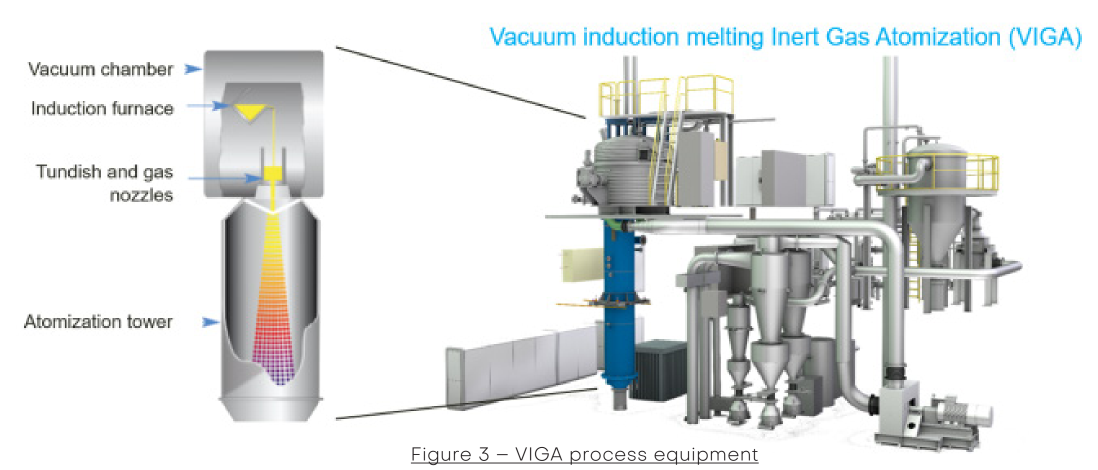


Figure 3 – VIGA process equipment

Pre-material: In most cases, the pre-material is scrap from flat product processing. The material is then cut into small pieces suitable for the process - typically 25 x 25 x 1~4 mm. These small pieces are then placed in the furnace crucible.

Melting: This takes place under vacuum conditions to avoid possible oxygen contamination and burning of important elements of the melt. It is possible to measure and control all the important process parameters such as temperature, pressure and vacuum. The melt can also be chemically analyzed to check if further alloying is needed to achieve the correct composition. When the melt is ready, the furnace is flushed with argon or nitrogen and the casting process begins.

Atomization: The melt flows through the tundish and is atomized into very small droplets by nitrogen or argon gas at high pressure and temperatures (up to 32 bar and 450 C°). The small droplets solidify in spherical form and fly through the pipes to the cyclone. Here, the solidified powder is separated from the gas and collected in the collection bins.

Sieving: The powder is separated into different fractions by mechanical sieving and an air classifier to target different powder metallurgy technologies. If, for example, a customer does not want to have more than 5% of their powder smaller than 20 µm, then the air classifier can be used to separate the smaller powders from the batch.

Why is the choice of atomization gas important?

There are four main reasons why an AM user might select nitrogen (N) or argon (Ar) as the gas to atomize their powders:

Price: Nitrogen is less expensive than argon. This has an impact on the price of the finished powder. Powder atomized using argon will be more expensive.

Morphology: Argon has a lower heat capacity than nitrogen. Therefore, powder atomized with argon has more time to achieve the desired spherical morphology before solidifying. Powders atomized using nitrogen solidify faster in a more irregular shape, although they are still highly spherical.

Proportion of fine powders: When atomizing a batch under the same temperature and pressure conditions, the proportion of fine powders – which are of interest for some AM technologies - is higher when using nitrogen. The full explanation for this is quite technical. But the simple reason is that nitrogen atoms are smaller, so at the same temperature and pressure, less energy is needed to divide the metal into a higher number of small droplets.

Powder properties: The mechanical and corrosion properties of powders can be influenced by the atomizing gas. For example, nitrogen can increase both the machinability and corrosion properties of printed parts.

Anti-satellite system makes a crucial difference

A crucial feature in powder production

is the anti-satellite system. Satellites are small droplets that adhere to the larger spherical particles – see Figure 4. To avoid this, argon or nitrogen is recirculated into the atomization tower. This gas pushes the very small droplets to the bottom and the likelihood of satellites in the solidifying particles is reduced.

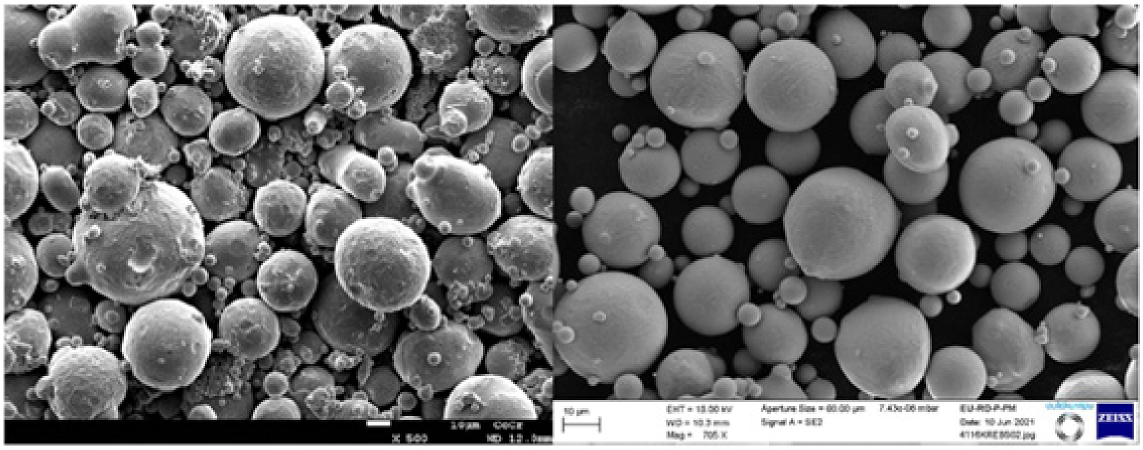


Figure 4 – a) spherical powder with a high amount of satellites b) spherical powder with a small amount of satellites

The presence of satellites rather than smooth, round powder will impact the quality of AM components in two ways:

Spreadability: The spreadability of the powder is decreased if it features satellites rather than perfectly spherical powders. This is important for the part of the process where the next layer of powder is spread onto the existing powder layer by the re-coater.

Morphology: Satellites reduce the apparent density and the packing of the powder. If the density of the powder is decreased there is a higher risk of failure in the AM process, due to pores or air gaps between the particles.

The need for a range of powder sizes

Each **powder metallurgy technology requires different powder sizes**. That is why powders are differentiated not only by the grade and the gas used for atomization but also the size. Powders up to 300 µm suit these AM and PM technologies:

· Binder jetting technology (BJT): <20 µm

· Laser powder bed fusion (PBF-LB): 15 to 45 µm and 20 to 63 µm

· Electron beam powder bed fusion (PBF-EB): 20 to 150 µm

· Direct energy deposition (DED): 20~45 to 150 µm

· Metal injection molding (MIM): <20 µm

· Hot isostatic pressing (HIP): 0-300 µm

Extending the scope of stainless steel grades

Currently, the stainless steel grades used most widely in AM and other powder technologies are 316L and 17-4PH. However, there are a number of new steel grades becoming available to the AM sector that are a closer match for the demanding requirements of high-performance applications.

The “commodity” stainless steels grades used in AM technologies are:

316L (1.4404): a low-carbon alternative to 316. This minimizes carbide precipitation as a result of heat input, for example during welding, giving improved resistance against intergranular corrosion. 316L/4404 is suitable for a wide variety of applications in the automotive, chemical, petrochemical and medical industries. Typical products include flanges, valves, and medical devices.

17-4PH (1.4548): a well-known martensitic precipitation hardening (PH) steel with alloying elements such as chromium or nickel. It has good corrosion properties and excellent mechanical properties up to

300°C. It is used in the aerospace, pulp and paper and nuclear industries for products such as mechanical seals, pumps or turbine blades.

Added-value special stainless steels grades include:

904L (1.4539): Special grade for high-corrosion environments. It is a high-nickel and molybdenum austenitic stainless steel with very high corrosion resistance. It was originally developed for handling sulfuric acid at ambient temperatures and is now used in a broad range of applications in the oil and gas and chemical industries. Typical parts produced from 904L are pumps, valves and flanges.

253MA (1.4835): Special grade for high-temperature applications. This is an austenitic stainless steel with excellent oxidation and creep resistance in cyclic conditions that is best employed in temperatures up to 1150°C. It is used in the oil and gas, aerospace and motorsport industries for parts such as fittings and heat exchangers.

1.4116: Special grade that is a high-hardness martensitic stainless steel with improved corrosion and wear resistance compared to other martensitic stainless steels. It is used in the healthcare and consumer goods industries for products such as medical devices and knives.

Nickel-free austenitic stainless steel powder (modified 1.4678): This specially-developed Ni-free stainless steel powder is an ideal substitute for 316L or Co-Cr alloys. It is also a perfect grade to avoid Ni-allergic reactions in health applications or consumer good applications for products such as watches and other items worn close to the body.

Nickel (Ni) - based alloys are also available:

Alloy 625: For use in very harsh, corrosive environments at high temperatures. Alloy 625 combines nickel, chromium, molybdenum and niobium that give excellent corrosion properties and excellent mechanical properties. When compared with Alloy 718, Alloy 625 has a greater overall resistance to oxidation. It is used in the oil and gas, aerospace and defense industries for components such as fittings, rocket parts, heat exchangers and vessels.

Alloy 718: This Ni-based alloy is also used for high corrosion environments and at high temperatures. It has additions of molybdenum, tantalum, aluminum and titanium that provide higher strength and better weldability, as well as improved stress corrosion cracking (SCC) resistance than alloy 625. It is used in the oil and gas, aerospace and defense industries for components such as fittings, rocket parts, heat exchangers and vessels.

Taking AM to the next level

The increased availability of stainless steel powders will open up new possibilities for designers who want to create AM parts that offer corrosion-resistance, durability and long life.

As a stainless steel manufacturer, Outokumpu is bringing its knowledge to the industry by launching a new business to support AM. This has included the commissioning of an atomization plant at our mill in Krefeld, Germany. This powder plant is effectively a large recycling unit that uses scrap resulting from existing production processes.

Large-scale 3D printed part produced on a Sciaky EBAM machine. Courtesy of Sciaky.

Electron Beam Additive Manufacturing is an ideal production candidate for large-scale parts, yet still lags far behind in adoption. Here is why.

In the metal 3D printing market, DED and LPBF are often the first technology processes that come to one's mind when looking to produce large-scale parts. Yet, behind the large-scale 3D printed parts built for the land, sea, air, and space industries, often lies an impressive **Electron Beam Additive Manufacturing** (EBAM) technology.

In such a process, the raw material (metal powder or wire) is placed under a vacuum and fused together from heating by an electron beam – unlike a selective laser sintering method where the powder melts layer by layer. Parts made using EBAM 3D printers are fabricated in a vacuum environment using extremely high temperatures of up to 1000 °C. This process delivers denser parts that tend to be more durable and that do not require any sort of post-printing heat applications.

Interestingly, there are a couple of EBAM technologies on the market. However, just as is the case with LPBF machines, all of them do not necessarily allow the production of large-scale parts. Sciaky on the other hand, a company that draws upon its electron beam welding expertise, is part of the exhaustive list of manufacturers providing an EBAM technology capable of producing large-scale parts.

Established in 1939, Sciaky was founded by a French family that received support from the US government to develop their business. In the mid-1960s, the manufacturer started developing the wire feed EB process as the main product. In the 1970s, they adopted the Electron Beam Welding technology that they gradually enhanced to help manufacturers save significant time and money on the production of large metal parts. 2009 saw the official launch of the EBAM process (which was then marketed as Electron Beam Direct Manufacturing) as a service option.

To date, Sciaky is a subsidiary of Phillips Service Industries, with about 50 employees operating from the headquarters in Chicago, and with several EBAM 3D printers across the world. As the company celebrates over two and a half decades of its EBAM technology, we caught up with **John O'Hara** to understand **EBAM's key specifications for large-scale parts, the reason why it is still overlooked and the commercial market of this technology.**

EBAM's key specifications for large-scale parts

Among the applications that I know Sciaky's EBAM enabled, I remember a titanium aircraft wing spar that stretched 12 feet in length (3.7m) and a huge titanium aerospace part that weighed over 3,000 pounds (1,360kg), which took 120 hours to build.

One thing we quickly learned from O'Hara is that the size can always be tailor-made. Since they custom build their welding systems, it was only obvious for the team to build tailor-made chambers for their EBAM machines. *"EBAM machines are typically made to order, with the sizes ranging in work envelopes of up to 6000mm x 2000mm x 1800mm as our largest machine, and our most common machine with a work envelope of 2000mm x 1100mm x 1500mm. EBAM is always done in a vacuum environment, which is ideal for reactive metals such as titanium, nickel, and refractory metals,"* **O'Hara** explains.

To manufacture metal parts comparable to those made with traditional manufacturing methods such as casting, designers and engineers need to keep in mind a couple of constraints they will need to monitor and address at the design level and during the manufacturing process.

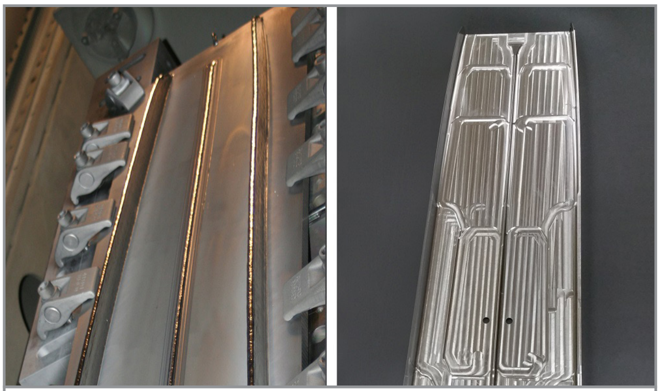
One of the considerations at the design level is that *"EBAM must always maintain the melt pool in a horizontal orientation, and must always print onto existing metal. This reduces the opportunities to print hollow cavities. The feature resolution of EBAM at best is 2mm features at low deposition rates, but will typically have a resolution of 8-12 mm,"* according to O'Hara.


A Sciaky EBAM 100 System – Courtesy of Sciaky

As concerns the material, due to its use of wire feedstock instead of powder, the technology can minimize waste and cost, resulting in significant savings. Furthermore, unlike powder metallic materials that are quite limited due to their expensive cost, there is a greater availability of wire products.

Like many industrial 3D printers – regardless of their technology, EBAM can also lead to quality issues due to potential changes in the process parameters, in the deposition process or uncontrolled settings in the build chamber. To continuously control and address these parameters, the company has developed a feature that is unique to its machines: a **process control system.** Named **IRISS®**, this option which stands for Interlayer Realtime Imaging & Sensing System, is placed inside the 3D printer. It can sense and digitally self-adjust metal deposition with precision and repeatability.

With almost no post-processing, and given the aforementioned features, EBAM seems to be the ideal production technology candidate. So, why is it still overlooked?


(Above) This photo highlights two different stages of an Airbus rear upper spar that was 3D printed in titanium with Sciaky's EBAM process. The image on the left shows the part in an early preform stage. The image on the right shows the finished part. Courtesy of Sciaky.

The reason why it is still overlooked and the commercial market of this technology.

For O'hara, the main challenge is to fund the qualification of their metal technology for production processes.

"As a manufacturer, we always pursue cost-saving measures. However, regardless of the industry, making a big part remains expensive. The biggest challenge for large format machines is that they are very expensive. The investment that you make is rather large in the development cycle and the operational investment should be proportional to the type of parts you want to produce," the Global Sales Director points out.

While EBAM lags far behind in adoption, compared to LPBF, *"these two technologies have no overlap, and are not in competition with each other,"* he adds. *"LPBF cannot make parts the size of EBAM, and EBAM is not economical to use on parts with ideal sizes for LPBF. LPBF has been available longer, and has many more companies working on advancing the technology."*

The million-dollar question that comes next is: how do we address this? Educating adopters on the potential of EBAM for large-scale parts is definitely one step to explore but it shouldn't be the only one. A big part of the work also lies in the development of applications that are not always harnessed in industries with the most stringent requirements. In the end, the more demanding the qualification requirements are, the more time it will take to achieve applications.

On another note, one road adopters could always take – regardless of their industry – is the one that leads to the AM service provider.

"Most people are interested in working with AM service providers. Most of the machines we sell are used for in-house applications. However, Sciaky can take on a production contract. We help our customers justify the cost of the machine, develop the technology for their own use as well as the material properties ideal for their applications," O'Hara concludes.

Start-up Area

ADDVANCE on the convergence of lean management and AM in a disrupted supply chain

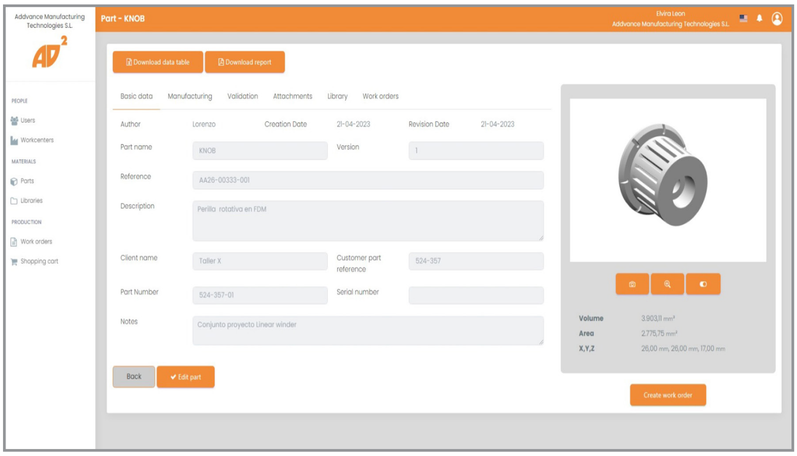
A general understanding of Additive Manufacturing (AM) and Lean Management (LM) will make most industrials agree on what seems an undisputable fact: AM can easily converge with LM as the former promotes resource efficiency and cost efficiency that the latter already provides. The problem is, since productivity has often constituted the basis of measuring operational excellence, thus the primary goal to achieve in industrial production, Small and Medium Enterprises (SMEs) have often failed to realize that although the advantages of AM are the same, different scenarios may apply to them when it comes to achieving series production with AM – in a more agile way. We recently caught up with ADDVANCE's CEO **Elvira Leon** to understand the mistakes they often make when trying to make their business agile with AM, and the areas where the company can provide its expertise to help them achieve this goal.

ADDVANCE is a Spanish company founded by three engineers with decades of experience in the industrial sector. Despite the advantages of AM, the founding team deplored the fact that the technology was difficult to integrate into industrial production environments. Three years ago, they started working on the development of a digital warehouse product, a **digital warehouse and on-demand manufacturing software**, which aims to guarantee traceability and facilitate the process both in internal manufacturing and with external suppliers and service bureaus. The team may have started operations on the Spanish market, but they now work with clients in Europe and America.

"Our mission is to provide a comprehensive solution to manufacture on demand, close to the point of consumption, ensuring quality and traceability without compromising the industrial property of OEMs. A digital and sustainable manufacturing, that allows the relocation of the industry. We focus on the industrial sectors (railway, automotive, machinery and industrial goods, among others) providing solutions for production and aftermarket operations optimization, supporting our customers in the creation and exploitation of their on-demand manufacturing business model, enhancing the digital warehouse with the additional functionality of process control to ensure regulatory compliance. In other sectors with relevant production or maintenance operations in distributed or remote locations (e.g. energy, Oil & Gas, infrastructures maintenance, naval, defense), we complement our offering with a local manufacturing solution, deployable smart micro-factories," ADDVANCE' CEO explains.

How LM and AM may influence each other

As far as lean management is concerned, companies often rely on an integrative approach consisting of human resources, machinery, strategies, and emerging technologies for maximized operating performance. While there is a lack of resources on how LM and AM complement each other, holistic experiences observed so far, reveal that when done well, the convergence of AM and LM easily enables **the manufacture of personalized products, increasingly demanded in a globalized and digitally connected world.** This is exacerbated by the fact that higher customer expectations lead



Author: Lorenzo
Creation Date: 21-04-2023
Revision Date: 21-04-2023
Part name: KNOB
Version: 1
Reference: AA26-00333-001
Description: Perilla rotativa en FDM
Client name: Taller X
Customer part reference: 524-357
Part Number: 524-357-01
Serial number:
Notes: Conjunto proyecto Linear winder
Volume: 3.903,11 mm^3
Area: 2.775,75 mm^2
X,Y,Z: 26,00 mm, 26,00 mm, 17,00 mm

to an increase in variant diversity and intensify the complexity of the production environment.

While the focus is made on AM, please keep in mind that LM can influence all technologies and processes of industry 4.0. (automated guided vehicles, virtual representation, human-computer interaction, cloud computing, big data & data analytics).

That being said, LM is often considered a prerequisite for the successful introduction of AM or industry 4.0 in general. This is supported by the fact that standardized, transparent and reproducible processes are of paramount importance for AM, therefore, executives need LM competence for considering customer value and avoiding waste. Furthermore, by reducing product and process complexity, LM enables the efficient and economic use of industry 4.0 tools.

On another note, industry 4.0 tools such as AM advance lean management as they rely on real-time data that improve transparency and information quality; not to mention that our industry continuously needs to cope with a fluctuating market demand that is influenced by a wide range of variables.

According to **Elivra Leon**, when looking to make their business agile, the difficulty for SMEs is often to find the applications or the business case, as they lack knowledge in the economic and organizational aspects of AM. *"There is a tendency to compare the current price per part in conventional technology with the price in AM, and the advantages in the pre-production stages or in the logistics chain are not considered. Once the applications have been identified and the possibility of managing their production through an on-demand manufacturing platform, managing their digital warehouse safely gives them flexibility and significant savings, and their competitiveness multiplies"*, Leon said.

This price comparison would be the major hurdle that would prevent an effective integration of AM into SME's supply chain. Leon adds:

"The nirvana of logistics is a process in which there are no stocks, and in which the parts or finished products reach the end customer, wherever he is, in the proper time it is needed. This is the basis for building a supply chain management strategy that aims to bring warehouse closer to the place of use. In this scenario, the combination of digital warehouse tools with additive manufacturing technologies is the solution to a new model of manufacturing on demand, for which a new agile supply chain must be designed. This model implies many changes in the way companies work nowadays and requires the implementation of new traceability solutions, but today we can say it is already feasible".

This means that to mitigate specific supply chain risks, manufacturing can distribute **geographically** (fabricating products at multiple locations, often close to the point of demand), **across the value chain** (fabricating the products by other entities, such as supplier networks or even customers) and over time (spreading production **over time** in specific quantities to meet sporadic and hard-to-predict demand).

Moving forward, to companies that are still looking to converge AM and lean management, ADDVANCE' CEO recommends following a few steps:

"First, carry out a feasibility analysis of the manufacturing model, assessing the benefits, challenges, and costs in implementation, both technically and economically. If the result of the analysis is positive, then identify the most appropriate AM technologies to carry it out, and consider internalization or externalize totally or partially, with external manufacturing suppliers. The key is to choose the optimal AM technology, as we know there are many different options, each of them suitable for different applications and materials.

Once the manufacturing model is defined, the implementation is simple. However, it is important to count with experts. Build a digital warehouse, a 'digital twin' of your physical warehouse, which collects all the information of parts and manufacturing process and operate it through a connected on-demand manufacturing platform, to assess an integrated, monitorable, and traceable process, and to guarantee the security of assets and intellectual property of the company."

2023
EVENTS

STAY UP-TO-DATE WITH THE LATEST ADDITIVE MANUFACTURING INDUSTRY EVENTS, CONFERENCES, EXHIBITIONS AND SEMINARS.

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

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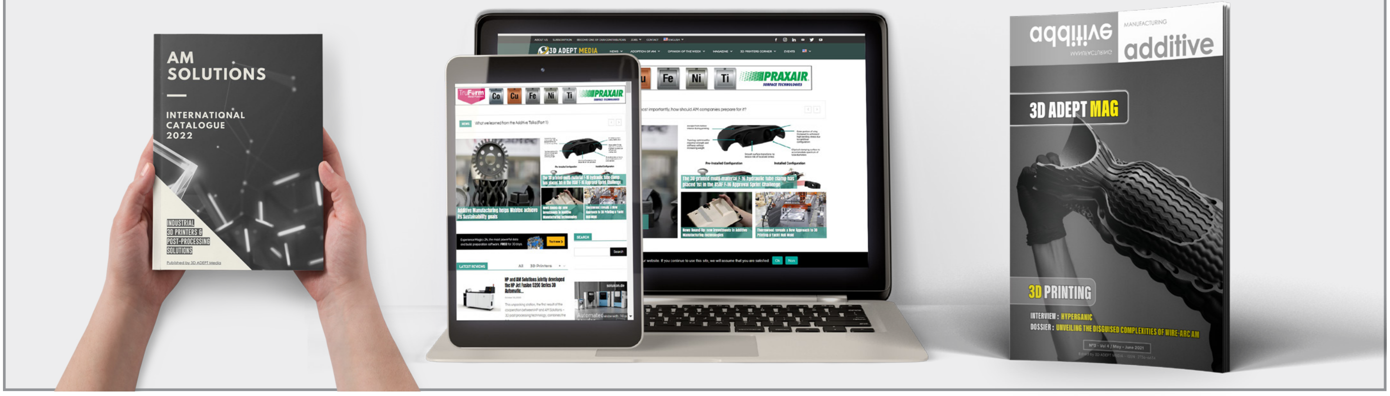

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