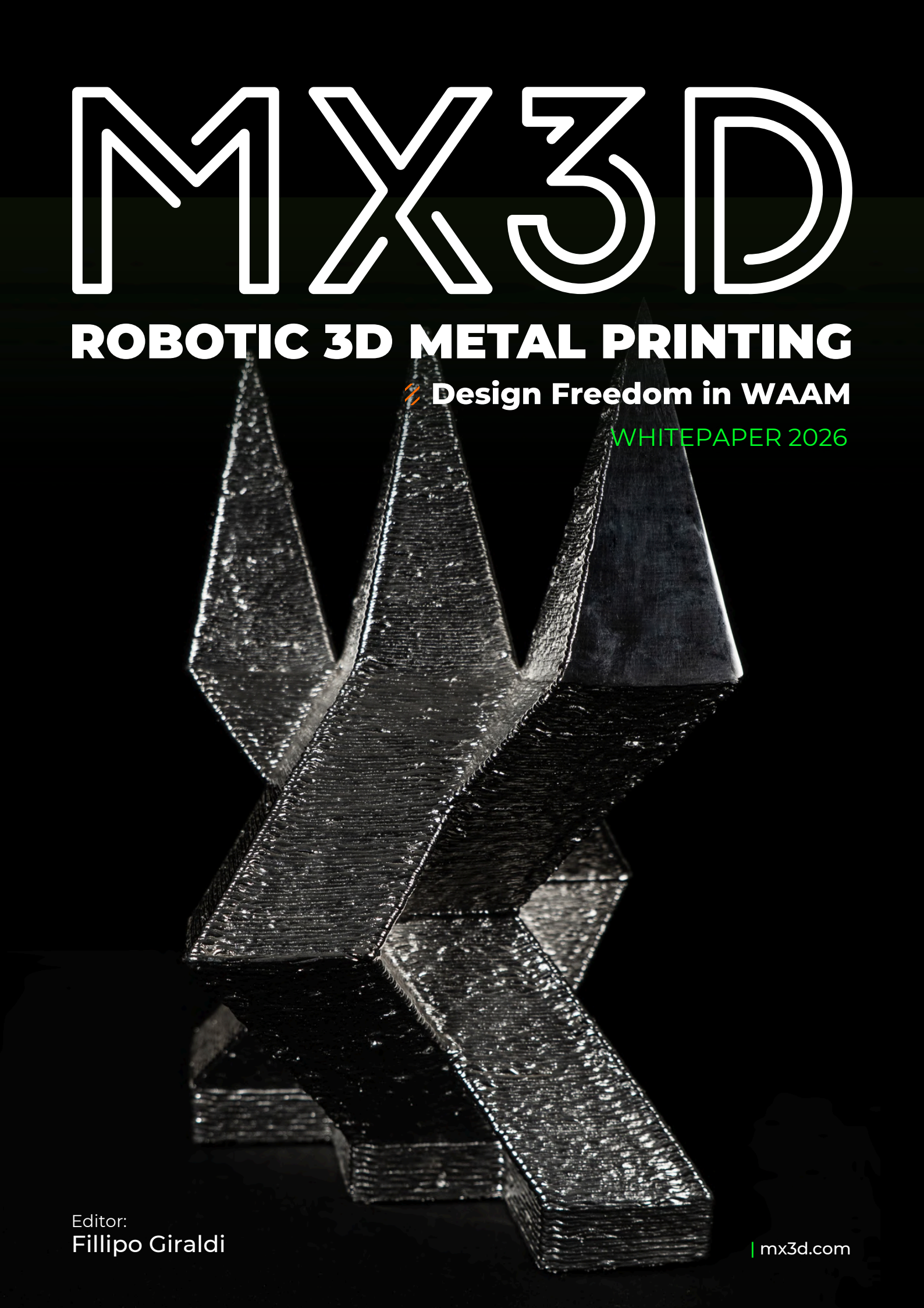
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ROBOTIC 3D METAL PRINTING

Design Freedom in WAAM

WHITEPAPER 2026



Editor:
Fillipo Giraldi

| mx3d.com

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The Evolution of Value: From ROI to Design Freedom

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In the whitepaper The ROI of WAAM, we established that Wire Arc Additive Manufacturing (WAAM) has matured from a technical novelty into a highly competitive industrial production method that can show tangible value. By optimizing deposition rates, integrating process automation, and significantly reducing lead times, WAAM delivers a measurable and robust return on investment (ROI). However, raw economic viability is only half of the equation.



Taking away manufacturing limitations

While a strong ROI proves that WAAM makes financial sense, the technology's ultimate value lies in its ability to fundamentally alter how we engineer and optimize heavy industrial components. This benefits both the cost and ecological footprint of manufacturing such parts.

Traditionally, engineers have been forced to design parts around manufacturing limitations of casting and forging, adding excess bulk to accommodate casting molds, simplifying geometries for subtractive machining, or splitting complex components into multiple pieces that must be welded together. WAAM flips this paradigm. By building components layer by layer on a massive scale, WAAM allows engineers to design strictly for structural performance rather than manufacturing convenience. This shift from economic efficiency to unconstrained design freedom represents the next major leap in large-scale metal manufacturing.



About the author

Filippo Gilardi, R&D Manager at **MX3D**, has been instrumental to the company's growth since its founding in 2014. With an M.Sc. in Industrial Design from Politecnico di Milano, he leads large-scale WAAM applications for the Nuclear and Aerospace sectors. Filippo specializes in process digitization, quality assurance, and design-for-additive strategies, having overseen landmark projects including the world's first 3D-printed steel bridge.

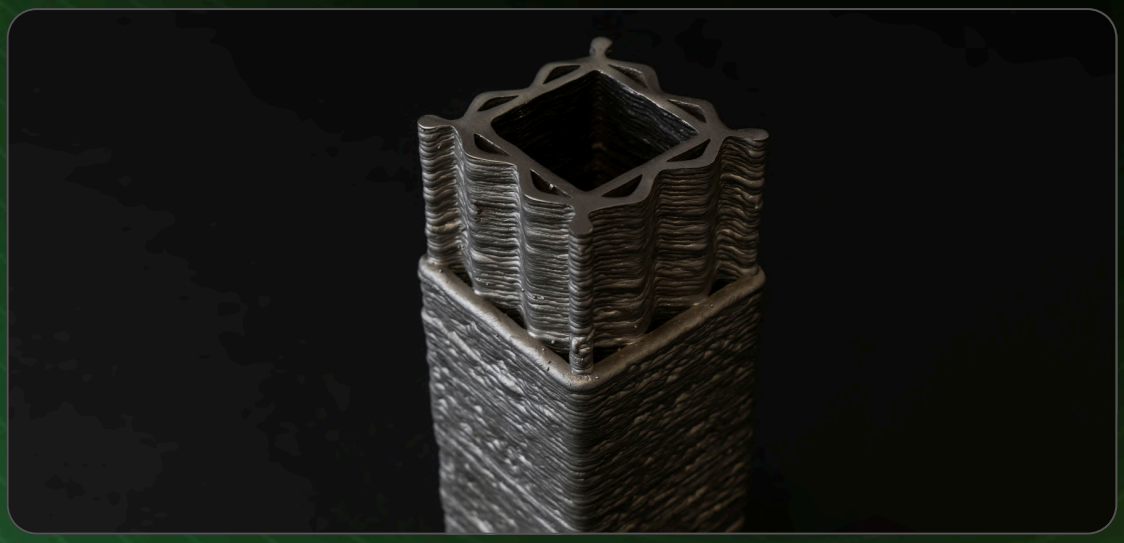
WAAM vs. Conventional Methods

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In traditional subtractive manufacturing (machining from a semi-finished casting product), geometric complexity directly correlates with cost and material waste. Removing internal material is often impossible without splitting the part, and achieving deep cavities requires specialized, expensive tooling. Similarly, casting requires the creation of molds and cores, limiting the ability to create varied wall thicknesses or otherwise topologically optimized features.

Unlocking Unrestricted Geometries

- Variable Wall Thickness: Engineers can design walls that seamlessly transition from thick, high-stress load-bearing sections to thin, lightweight areas without requiring secondary machining.
- Complex Internal Channels: Hollow structures and internal cooling channels can be integrated directly into the part, improving thermal management and reducing overall part mass.
- Support-Free Architectures: Unlike powder-bed additive manufacturing, WAAM can often achieve overhanging geometries using self-supporting angles, eliminating the need for support structures.
- Metallurgical Freedom: Beyond geometry, WAAM offers immense material flexibility. Because the process utilizes standard industrial welding wire, most weldable metal wires, including carbon steels, stainless steels, duplex, bronze, aluminum, and high-strength alloys, can be deposited to meet exact performance requirements.
- Multi-material: WAAM enables the seamless deposition of multiple compatible alloys within a single monoblock component. This allows engineers to locally tailor material properties, such as prioritizing high structural strength in the core and extreme corrosion resistance on the exterior, without the thermal vulnerabilities of welding separate parts. For instance, printing a base part with ER70 and doing the cladding with Inconel 625.



Internal geometric complexity: WAAM enables hollow structures and variable wall thickness

Thanks to WAAM, subtractive manufacturing can be relegated to a last-step finishing method to further refine a WAAM part and selectively bring specific areas down to fine tolerances.

Design Optimization and Material Efficiency

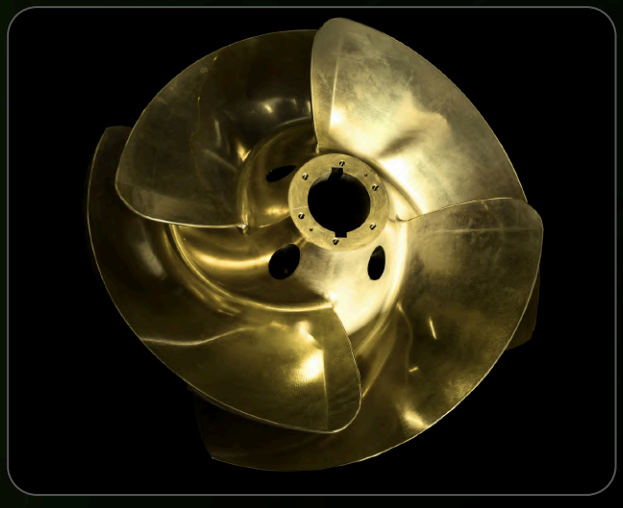
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The greatest advantage of layer-by-layer robotic deposition is the ability to place material where the physical loads demand it. When combined with computational generative design, this leads to advanced design optimization. This commonly results in high-performance components that offer valuable advantages over traditional methods:

- Extreme Material Efficiency: Traditional subtractive methods can have Buy-to-Fly (BTF) ratios of 10:1 or even 20:1. WAAM drives this down to 1.2:1. For example, if a conventional method requires a 500 kg solid billet to CNC machine a 50 kg final part, 450 kg of raw material is wasted. Using WAAM, you might deposit just 60 kg of material to reach the same end result, reducing waste by a factor of 45x.
- Weight Reduction: By removing "dead weight" that does not contribute to load-bearing, components become significantly lighter.
- Superior Performance-to-Weight Ratio: Lighter parts directly translate to lower material costs, cheaper logistics, and improved operational efficiency.
- Cost reduction: for instance, requiring 50% less material to create a 1-ton Inconel part directly reduces the cost of manufacturing significantly.

Case: The Engie Impeller

An example of WAAM material efficiency is the 350 kg nickel-aluminum bronze impeller produced by MX3D for ENGIE. Traditionally, machining this complex geometry from a solid forged round billet would require approximately 2,500 kg of raw material, resulting in 2,150 kg of waste. By utilizing WAAM, MX3D deposited 500 kg of material to yield the final part, reducing material waste to only 150 kg.



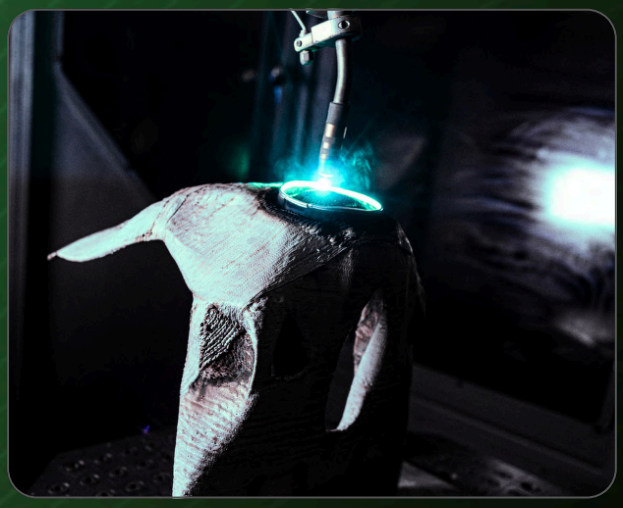
Rapid Manufacturing

This impeller was printed in just 9 days. Even factoring in two weeks for final CNC milling, this approach bypassed the months-long lead times associated with complex casting molds or heavy forging. While this initial project was a "like-for-like" dimensional copy rather than a weight-optimized design, a common first step for clients validating the technology, the immediate material and time savings are undeniable.

The ENGIE Impeller: A 350 kg component printed in just 9 days, proving that when heavy post-machining of cast parts is required, WAAM is the superior alternative.

Functional Optimization and Structural Integrity

Design freedom is not only about making a single part lighter; it is about rethinking entire components to maximize structural and operational efficiency. WAAM allows engineers to leverage topology optimization and generative design to create highly optimized printed components that outperform traditional iterations.



BMW Strut Tower
WAAM's potential in automotive manufacturing is the suspension strut support produced by the BMW Group using MX3D technology. While structural components of this nature often rely on expensive die-casting molds, BMW Group successfully utilized WAAM to produce a highly optimized strut support for extensive test bench comparisons against a die-cast aluminum series counterpart.

By evaluating the WAAM strut support, the engineering and operational benefits became clear:

- High Cyclic Load Endurance: BMW demonstrated that the WAAM components can successfully endure high, cyclic loads on the test bench without the need for complete post-processing or milling of the surface, proving the raw printed structure is inherently robust.
- Weight & Material Efficiency: Combining generative design methods with WAAM technology ensures a remarkably low material usage rate, which significantly reduces the overall weight of the final part.
- Sustainable Production: By eliminating the need for heavy die-casting tooling, minimizing raw material waste, and leveraging the possibility of using green electricity, WAAM drastically lowers manufacturing emissions and front-loaded costs.



"Even in this early phase of technology enablement, it is clear that the WAAM process can lead to lower emissions in the production process. The components can be produced more efficiently thanks to their lower weight, low material usage rate, and the possibility of green electricity."
— Jens Ertel, Head of BMW Additive Manufacturing

Part consolidation in automotive: The MX3D and BMW Group suspension strut tower.

Design for WAAM (DfAM): Maximizing Deposition Rate Efficiency

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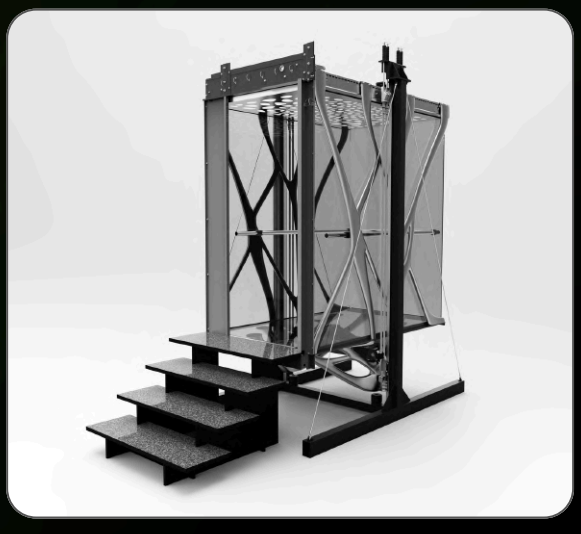
While extreme operational savings or strict supply chain necessity can sometimes justify a costly manufacturing process, most complex geometries must be printed efficiently to maximize ROI.

This makes Design for Additive Manufacturing (DfAM) critical. It is a missed opportunity not to design a part, utilizing the possibilities of optimization that Additive Manufacturing has to offer. By reducing weight, the cost and lead time for producing a part are lowered directly and quite linearly.

To maximize this weight optimisation, engineers must align their FEM analysis with the physical realities of the WAAM process. Here below you find some ground rules:

- Continuous Toolpaths & Consistent Mass: Designs that allow the robot to print in long, continuous loops significantly reduce idle time. Furthermore, avoiding abrupt changes in cross-sectional thickness ensures even heat distribution, preventing residual stress and part distortion.
- Minimizing Starts and Stops: Every time the arc stops, the system must manage cooling, gas shielding, and repositioning. Designing to minimize these transitions speeds up the build.
- Optimal Wall Thickness: Maintaining a regular wall thickness throughout elements guarantees stable deposition at efficient speeds.
- Smart Hole Design: Horizontal holes should be designed as droplet shapes to naturally support themselves as they print. High-precision features, such as threaded or functional holes, should be printed solid and machined afterward.
- Leveraging Self-Supporting Angles: A major advantage of WAAM is the ability to print complex geometries without wasteful support structures. While a 45-degree overhang is a safe standard benchmark, the use of advanced 5-axis rotating tables and specific alloys often allows engineers to push overhangs up to 60 degrees.

By designing with the process in mind, engineers ensure that their complex geometries do not bottleneck production, maintaining the high deposition speeds that make WAAM profitable.



Schindler elevator.



Robot Arm.

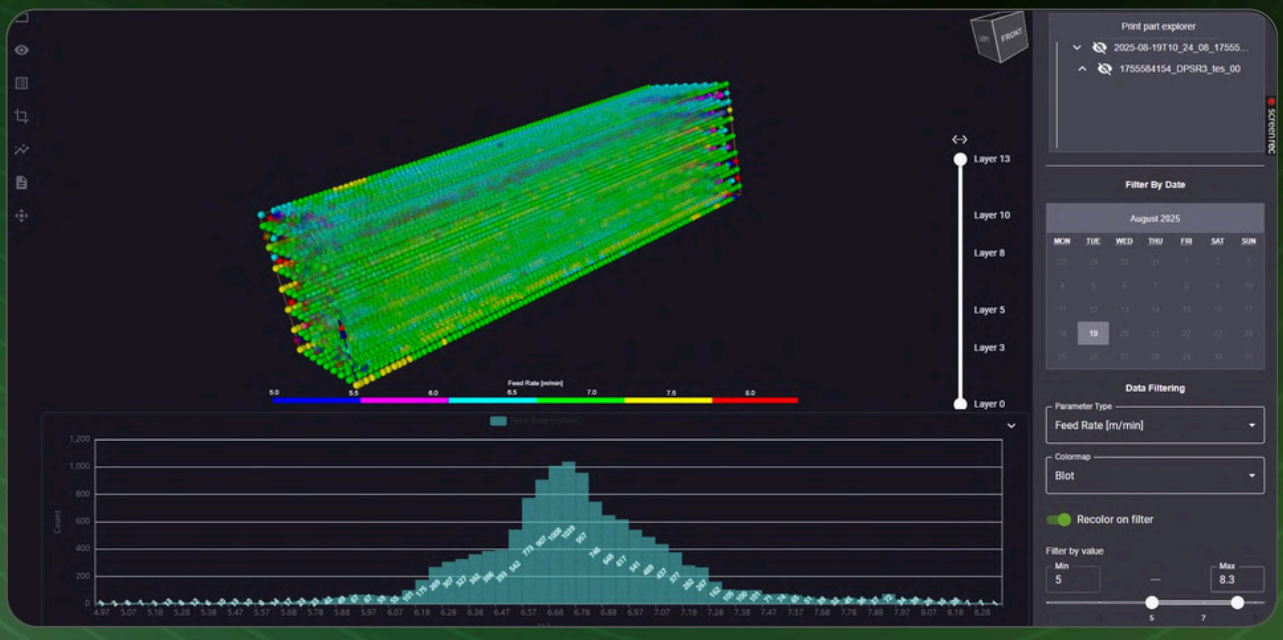
Bridging Design and Production: The Role of MetalXL

Design freedom presents a unique challenge: complex topology is useless if the robotic system is not programmed to print it. The bridge between a CAD design and a physical, structural metal part is advanced software.

Software platforms like MetalXL are necessary to translate optimized, intricate designs into stable, manufacturable robotic toolpaths.

- Managing Process Constraints: While the CAD model might suggest an impossible feature, the software ensures the operator respects the physical realities of waam printing like bead width, heat accumulation, and overhangs.
- Path Optimization: The software automatically calculates the most efficient route for the robot, minimizing “air-time” and ensuring the continuous paths discussed in Chapter 5 are followed.
- Predictive Control: By simulating the print digitally before striking an arc, engineers can verify that their generative designs will not be affected by thermal stress or cause torch collisions in tight, complex geometries.

MetalXL ensures that the freedom experienced in the digital design phase is turned into a high-quality, repeatable physical print.



MetalXL Parameter Coltrol Visualization of a Printed Wall

Conclusion

Wire Arc Additive Manufacturing is replacing traditional manufacturing in many different industries. Aside from the lead time, the design possibilities give WAAM another significant edge.

By removing the constraints of subtractive tooling, casting molds, and multi-part assemblies, WAAM grants engineers the freedom to design strictly for performance. Through topology optimization, material is placed only where necessary, drastically reducing component weight and material waste. Through part consolidation, complex assemblies are unified into single, stronger parts, eliminating mechanical failure points and streamlining supply chains.

When these unconstrained designs are optimized for high deposition rates and executed through advanced control software like MetalXL, the result is a production methodology that delivers the best of both worlds: efficient, lightweight, and structurally superior components produced at relatively high speed. WAAM represents the ultimate alignment of economic efficiency and engineering freedom.



The MX, M1, MD and MB WAAM systems of MX3D

If you would like to know more about material properties of WAAM for your own part or if you have a system inquiry, reach out to MX3D to evaluate feasibility, performance, and business impact based on your specific application.

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