REALISING PRECISION THROUGH INTENT, INSIGHT AND ITERATION

In the area of precision engineering – where tolerances are measured in microns or even nanometers – additive manufacturing (AM) offers a new level of possibility. But the value of AM is not unlocked by printing alone. True performance at the micro- and nanoscale requires thoughtful design, clear engineering intent, and a process that can accommodate complexity without sacrificing manufacturability. In this context, Design for Additive Manufacturing (DfAM) must evolve into something more than a mechanical exercise in material removal or stress distribution.

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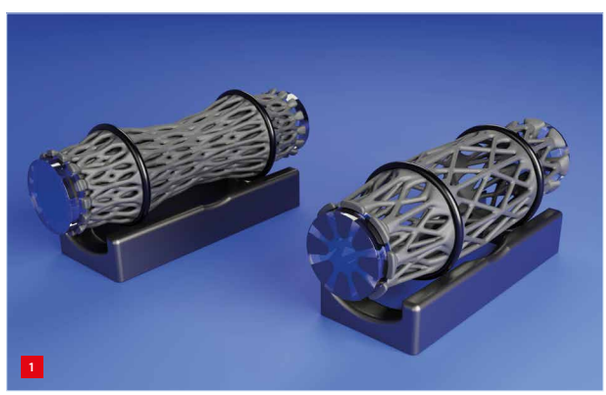
At Metamorphic, we believe the future of DfAM lies in balancing engineering intent, computational design and real-world constraints. The approach should be an integration of cutting-edge tools when they add value – including multi-objective optimisation, machine learning and simulation – but it is rooted in a clear understanding of the problem, the application, and the capabilities of the manufacturing process. In other words, you start with good design, and then use digital tools to make it even better.

From capability to intent

The AM industry is often framed by what's possible – "Look at what we can print!" – but possibility is not the same as purpose. The most successful AM projects begin not with the tool, but with the intent. What function must this part perform? What conditions must it withstand? What tolerances are truly critical? These are the questions we ask at the start of every project.

Designing with intent means understanding not just what a component needs to do, but how it will behave under real-world conditions. In high-precision contexts, seemingly small considerations – such as anisotropic stiffness, thermal drift or vibrational response – can become defining factors in performance. And those factors must be built into the design process from the beginning.



CAD render of two optomechanical structures optimised for different objectives.

Rather than defaulting to generative or automated tools, Metamorphic favours an approach where form is derived from function. This enables the development of structures that are not only efficient in terms of material, but also stable, robust and predictable when manufactured and deployed.

Computational design in context

That said, there is enormous value in computational design, when it is used in context. Many projects benefit from advanced simulation, geometry exploration or automated trade-off analysis. But these tools are not a substitute for good engineering, they are a way to support and enhance it.

For example, in the development of opto-mechanical components, parametric modelling combined with finite-element analysis can be used to understand how design changes impact optical misalignment due to thermal expansion, mass distribution and modal frequencies. These insights inform decisions, allowing the balancing of competing constraints such as rigidity and weight, or accuracy and manufacturability.

In some cases, multi-objective optimisation can be applied – not to blindly generate final designs, but to identify promising design spaces and understand how sensitive the system is to certain parameters. This is especially useful when working with conflicting requirements, such as achieving both thermal stability and structural compliance, or maximising stiffness while maintaining low mass.

AUTHORS' NOTE

Laurence Coles and Manolis Papastavrou are the founders of Metamorphic AM. Located in Derby (UK), Metamorphic provides tailored design consultancy services to organisations that want to evolve and accelerate their R&D through the use of AM.

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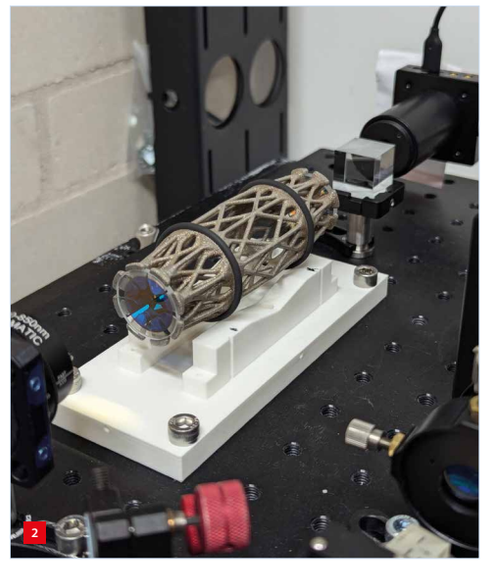
When used iteratively and interactively, these tools can accelerate convergence on a viable design, rather than leading the process blindly. The result is a more transparent, collaborative workflow that gives both engineers and clients confidence in the direction a project is taking.

Machine learning

ML (machine learning) is a powerful tool, but like all tools, its value lies in its application. ML-enabled workflows can be developed that assist in material selection, geometry prediction and printability assessment. But it is important not to oversell what ML can do – especially in a field where real-world data is often sparse and highly context-specific.

Machine learning does not replace domain knowledge. It augments it. ML should be embedded selectively, using it as a source of insight that feeds back into the engineering process, not as a black-box decision maker. And where data is limited or uncertainty is high, you should fall back on physics-based modelling and empirical testing – because reliability always comes first.



Additively manufactured optomechanical structure in Invar36 undergoing testing to assess optical stability under varying environmental conditions. (Project Ref: ORSAM - 3D Printed Structures for High Finesse Cavities (IUK 10036095))

Manufacturability

One of the most overlooked aspects of DfAM is the transition from digital design to physical part. A geometry that performs well in simulation can still fail in practice if it is too thin to print reliably, too complex to support, or too sensitive to post-processing variability. That is why manufacturability should be brought into the design loop from day one. Printing should not be treated as a final step; it should be treated as a constraint and an opportunity throughout the design process.

In practice, this means collaborating closely with manufacturing partners to understand their process windows, machine limitations and post-processing capabilities. Allowances for distortion, support removal and surface finishing should be built in. In critical applications, likely print deviations should be simulated – including thermal warping, residual stresses, dimensional variability and surface roughness – and designs adapted accordingly.

One technique that has been shown to be useful is stochastic modelling, introducing randomised geometric perturbations to simulate how manufacturing variability might affect performance. This allows the robustness of a design to be tested 'in silico' before committing to expensive builds. By doing this work up front, rework is minimised, risk reduced, and confidence is improved that the printed part will meet functional requirements – not just in theory, but in reality.

Materials as a design parameter

As AM materials evolve, they bring new opportunities and new design challenges. Alloys developed for AM, for example, may have unusual thermal expansion behaviour, build anisotropy, or post-processing requirements. Designing effectively with these materials requires more than swapping one spec sheet for another; it means understanding how material behaviour interacts with geometry and function.

At Metamorphic, we are developing advanced workflows to optimise material selection and distribution strategies for precision systems. Beyond conventional single-material approaches, we explore how multi-material configurations influence performance, stability and efficiency. By analysing how different materials interact within a system, we identify cases where a strategic distribution – rather than relying solely on the best individual material – yields superior results. To ensure robust optimisation, these complex workflows must be properly bounded, allowing for informed comparisons and precise material selection tailored to each application.

In future, we expect this kind of material-geometry co-design to become the norm. As machine learning models mature and material databases grow, it will be possible to treat material selection as an optimisation variable rather than a fixed input – giving designers even greater freedom to balance performance, cost and manufacturability.

Precision design challenges

In high-precision engineering, the design process often involves navigating complex trade-offs – for example, reducing mass without sacrificing stiffness, or ensuring dimensional stability in the face of thermal and mechanical loading. These are not challenges that can be solved by algorithms alone. They require clear engineering

intent, careful analysis, and a practical understanding of how parts behave in the real world.

The path forward

As AM matures, so too must the way we approach design. The promise of complexity and customisation is real – but so are the risks of overengineering, overreliance on software, and underestimating manufacturing realities. Success is predicated on blending computational design, simulation, and real-world experience to create precision components that work – not just in CAD, but in the lab, on the production line, and in the field.

"Excited about the future"

At Metamorphic, we specialise in helping clients address their (precision) design challenges through a design-led, consultancy-driven approach. Rather than relying solely on automated optimisation tools, we focus on developing well-considered designs that reflect functional requirements and are grounded in manufacturability from the outset.

We use simulation and design exploration to understand performance trade-offs and guide decision-making, but we also work closely with manufacturing partners to ensure those designs are viable in production. Whether the goal is to control deflection, manage heat or reduce vibration, we help clients make the right compromises – and avoid costly trial & error. By combining good engineering with the right use of computational tools, we support the creation of parts that perform reliably under demanding conditions and are deliverable within the realities of AM.

We are continuing to build our methods, tools and capabilities. That includes more advanced optimisation strategies, better simulation integration and smarter material data workflows. But what will not change is a focus on good engineering – on understanding the problem first, and solving it with the right mix of tools and thinking. We are excited about the future – not because of what the software can do, but because of what we can do with it.