Designing For Additive Manufacturing

How engineers can use this new technique to gain freedom from conventional design constraints

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Introduction

Additive manufacturing (AM), or 3D printing, is growing faster than ever before. The total market for AM products and services is currently $4 billion. Depending on which industry analysts are making the projection, this number is expected to increase anywhere from 2x to 100x in the next decade. Nearly all of this growth is expected to happen in the industrial sector as manufacturers supplement traditional equipment with AM devices.

It's easy to see why AM is so popular. Its freedom of design is virtually unlimited. While the specifics of each technique vary, they generally involve creating 3D objects by building up layers of material under the direction of a computer. Essentially, AM allows designers to create product geometries that would be impossible to produce using conventional means.

But total freedom brings its own particular challenges. Specifically, it raises two issues that engineers have never had to grapple with before.

First, modeling designs for products that will be 3D printed is nearly impossible using computer-aided design (CAD) tools that have been tailored to fit traditional manufacturing techniques. Second, even if you were able to model these designs, the number of viable options for any project is astronomical. Practically speaking, it is impossible to fully evaluate all of them, which means opportunities to fulfill the requirements of the project will remain undiscovered.

It may seem at first that engineers have unprecedented freedom but no way to use it. Fortunately, this is not at all the case. Engineers in numerous industries are applying AM in consistent, useful ways. In this eBook, we will take a look at three of these strategies to provide an overview of how to think about AM and capitalize on it in your own work.

THREE KEY OPPORTUNITIES

Additive manufacturing techniques are driving three important outcomes for engineers.

Part consolidation

The fuel nozzle for the LEAP jet engine consolidated 20 components into a single, 3D-printed part.

Some of the most challenging parts to produce are those that involve many separate components, each of which has to be designed, sourced, assembled, and maintained. These complex supply chains are expensive and difficult to manage. Plus, each part in the assembly is a potential point of failure, one that must be tested, validated, and monitored over time. Ideally, engineers would rather design one part that serves the same function rather than break the job up into pieces. But in many cases this isn't possible.

This is what GE experienced with the fuel nozzle for a new, fuel-efficient jet engine. The efficiency of the engine depended entirely on a complex nozzle that would spray fuel into the combustor. The nozzle had more than 20 parts that needed to be welded together.

Engineers from CFM International, a joint venture between GE Aviation and a French aircraft manufacturer, worked in secret to see if AM could solve the problem. And it did. Printed from nickel alloy, the new nozzle consolidated all 20 components into a single part that weighed 25% less than a conventional nozzle and was five times as durable.

This breakthrough product made a huge impact. It quickly moved into mass production as part of the LEAP, one of the best-selling jet engines in CFM's history. GE opened a 3D printing factory for the nozzles. And as of October 2017, orders for the engines reached $170 billion.

Lightweighting

The demand for lighter products grows every day as engineers seek to design products that use less material while meeting specifications for strength and durability. Typical examples of lightweighting occur in automotive and aerospace manufacturing, where small differences in weight result in dramatic reductions in fuel costs.

Recently, for example, United Airlines began using a lighter grade of paper for its inflight magazine, reducing the total weight of each issue by one ounce. The cumulative savings for the entire fleet, which runs 4,500 flights a day, is approximately 170,000 gallons of fuel per year, or $290,000.

Lightweighting can make a difference in everyday industrial products as well, thanks to AM. At Stanley Black & Decker, one engineering team focused on a high-tension wire crimper attachment. Electricians typically use this product overhead while standing in a bucket truck. As you can imagine, the attachment was very heavy because it had to withstand 135kN of force in service.

Using generative design, the team at Stanley Black & Decker reduced the weight of the crimper 42%, from 2.4kg to 1.4kg, then decreased it another 60% to just 0.95kg. Because the new attachment weighs less, it is much easier for electricians to use.

Performance enhancement

Interlocking lattice structures deliver a unique combination of strength and flexibility.

AM and its attendant techniques give engineers more ways to achieve gains in flexibility, strength, stiffness, and heat dissipation.

At Under Armour, the company identified a need to combine the qualities of a heavy weightlifting shoe and a cross-training shoe, enabling athletes to perform both activities equally well without swapping out their footwear.

The innovation in the Architech shoe is a 3-D printed midsole with a dynamic lattice network that uses two interlocking structures. The design of the midsole delivers the particular balance of support, stiffness, and cushioning that product designers were looking for, while enabling energy return with every step. Generative design allowed Under Armour to test numerous patterns and spacing of the lattice structures in order to find the ideal result for the shoe's performance requirements. The end result is the company's first shoe with a 3D printed component.

Three paths to follow

For any of these outcomes, engineers have several design options to pursue. In the next three chapters, we'll take a look at three approaches that work very well with the unique capabilities of AM. They are:

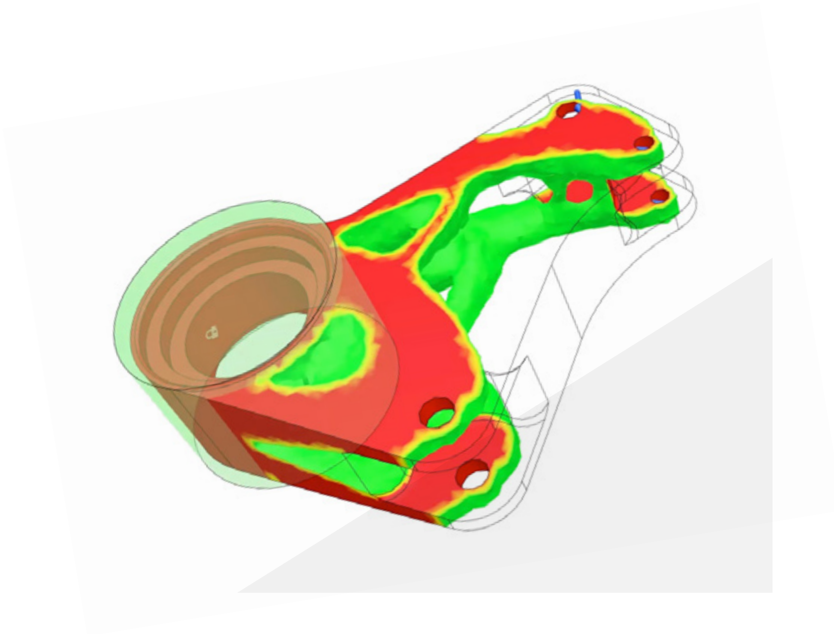
1 Topology optimization

2 Latticing

3 Generative design

TOPOLOGY OPTIMIZATION

Generate forms optimized for stiffness and weight based on the loads and constraints of the part.



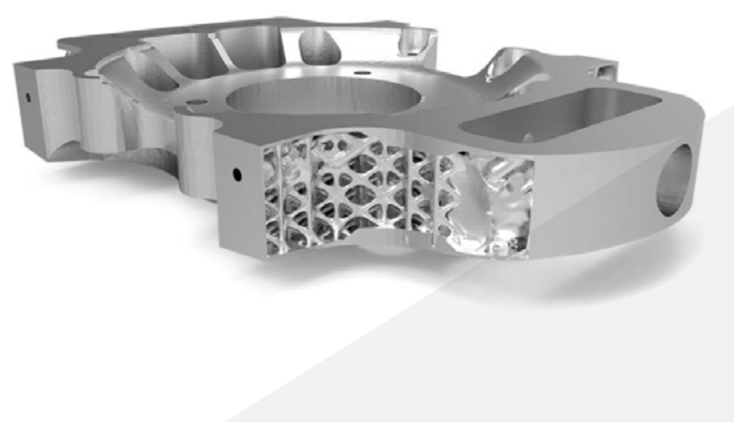
Topology optimization is a familiar technique for most engineers that has gained new life with the possibilities of additive manufacturing.

In general, topology optimization is an analysis of a part that removes material that does not affect its functionality. In other words, you specify where a part attaches and what loads it needs to withstand in service, and a topology optimization tool identifies and eliminates as much material as you specify while still meeting your stress and displacement objectives.

The result is usually a complex, intricate, almost organic-looking design that is extremely efficient. It weighs less and delivers the same amount of strength and stiffness. It is also very expensive (or impossible) to manufacture with conventional equipment, such as CNC machining.

Enter AM, with its ability to produce previously unmakeable designs. AM is a perfect fit for topology optimization. Instead of removing excess material, you simply add only what is required.

More advanced topology optimization engines can do even more. They can factor in manufacturing constraints. For example, if a part must be extruded, the tool can keep a consistent profile in a single direction. If the part will be machined, the tool can factor in cutter accessibility. If it will be molded, separation into halves can be added as a constraint. These tools can even take material properties into account. All of this helps engineers accurately weigh the costs and benefits of AM and more conventional approaches before converging on the ideal design.



LATTICING

Use innovative cellular structures to achieve unique combinations of strength and flexibility.

One notable example of the latticing technique was accomplished at Pier 9, Autodesk's technology center in San Francisco. There, research scientists developed a unique aircraft seat frame that could easily fit in any commercial jet, yet it looks unlike any conventional seat frame because Autodesk's Netfabb software created the seat's geometry to meet lightweighting goals via latticing.

The resulting design is just as strong as any other frame but much lighter. The pattern for the design was 3D printed in acrylic to create an investment casting mold, and then cast in two metals. The aluminum frame reduced total mass by 29.5% and the magnesium frame reduced it by 56%. Both designs could help airlines save millions annually if they were integrated into the entire fleet.

Instead of solid structural beams, the generatively designed seat frame has a bridge with hundreds of smaller lattice cells and several thousand small struts that vary in thickness to bear local loading conditions.

One major difference between additive manufacturing and more conventional techniques, such as CNC machining, casting, and injection molding, is its ability to tolerate complexity. Because each part is built up in layers, parts can be made with incredibly intricate cellular or “latticed” structures without any special setup or additional steps.

Lattices are highly versatile. The size, shape, and arrangement of individual cells can be manipulated to deliver a wide range of performance characteristics that blend strength and flexibility in a lightweight design, similar to the 3-D printed midsole of the Under Armour shoe.

Latticing can be done in a variety of ways, depending on the engineering goal. Like topology optimization, latticing is an ideal way to reduce the overall weight of the part to minimize material cost and shorten production time. This non-structural approach typically uses a uniform lattice structure to remove unnecessary material.

Latticing can also be done to remove weight and withstand specific service loads. This structural approach generally uses a non-uniform lattice structure, in which the thickness of struts and the “skin” of the lattice are varied to support the actual loading conditions.

GENERATIVE DESIGN

Explore more designs and overcome common assumptions about form and structure.

For most engineers, one of the most frustrating aspects of additive manufacturing is that while the techniques create a great deal of freedom, the ability to take advantage of this freedom is limited by traditional CAD software. These platforms were intended to support the design of products made through conventional means, whether machining, casting, or molding. As a result, many are not well equipped to create the ornate and highly complex structures that are a natural fit for AM.

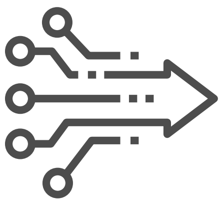
Generative design tools are starting to alleviate this frustration by helping engineers transcend the limits of traditional design thinking. These tools do this by synthesizing forms based on inputs about performance, material, or manufacturing characteristics—as opposed to starting with a preconceived idea of how a product should look and behave.

In other words, instead of drawing a design based on what you know, you tell the generative design tool what you want to accomplish. You start by indicating what the product should achieve (such as minimizing weight or maximizing durability), what the product should do (how much weight it must support or heat it must withstand), and the degrees of freedom the tool has to generate the outcomes (allowed manufacturing processes or materials).

This approach, which mimics natural evolution, delivers a great deal of insight about the possibilities of the product's design. The benefits are considerable:

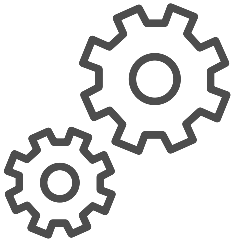
More design options.

Generative design will inevitably produce options that engineers could not have imagined independently, setting the stage for innovation.



Additive alignment.

Generative design tends to produce designs with complex internal structures that can only be made with AM techniques.



Optimization.

By establishing the product's parameters up front, generative design automatically resolves conflicting design requirements. This makes it easier for engineers to select a design direction and further refine as project needs dictate.

CONCLUSION

Use the freedom of AM to achieve specific project goals.

It can be overwhelming to shift your perspective from conventional approaches to the complex world of additive manufacturing. With fewer rules and exponentially more freedom, how can you find enough focus to work efficiently and achieve cost-effective outcomes?

The answer is likely to concentrate on the demands of a specific project. Does it need fewer components? Does it need to weigh less? Does it need to be stronger or more flexible? One of the most exciting possibilities of additive manufacturing is the ability to start with what the product needs, then conceive more design possibilities and create highly complex shapes that meet these goals.

Using the techniques described in this eBook is getting easier and more convenient all the time. New software applications combine topology optimization, latticing, and generative design tools to offer a more integrated experience. With all of these capabilities working together, engineers can concentrate on how the product should work—what it should do and how well it should do it—and let additive manufacturing make that idea a reality.

Get Started

To learn how Autodesk software can help you capitalize on all the opportunities of additive manufacturing, visit our Resource Center.

See resources

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