Additive manufacturing, explained

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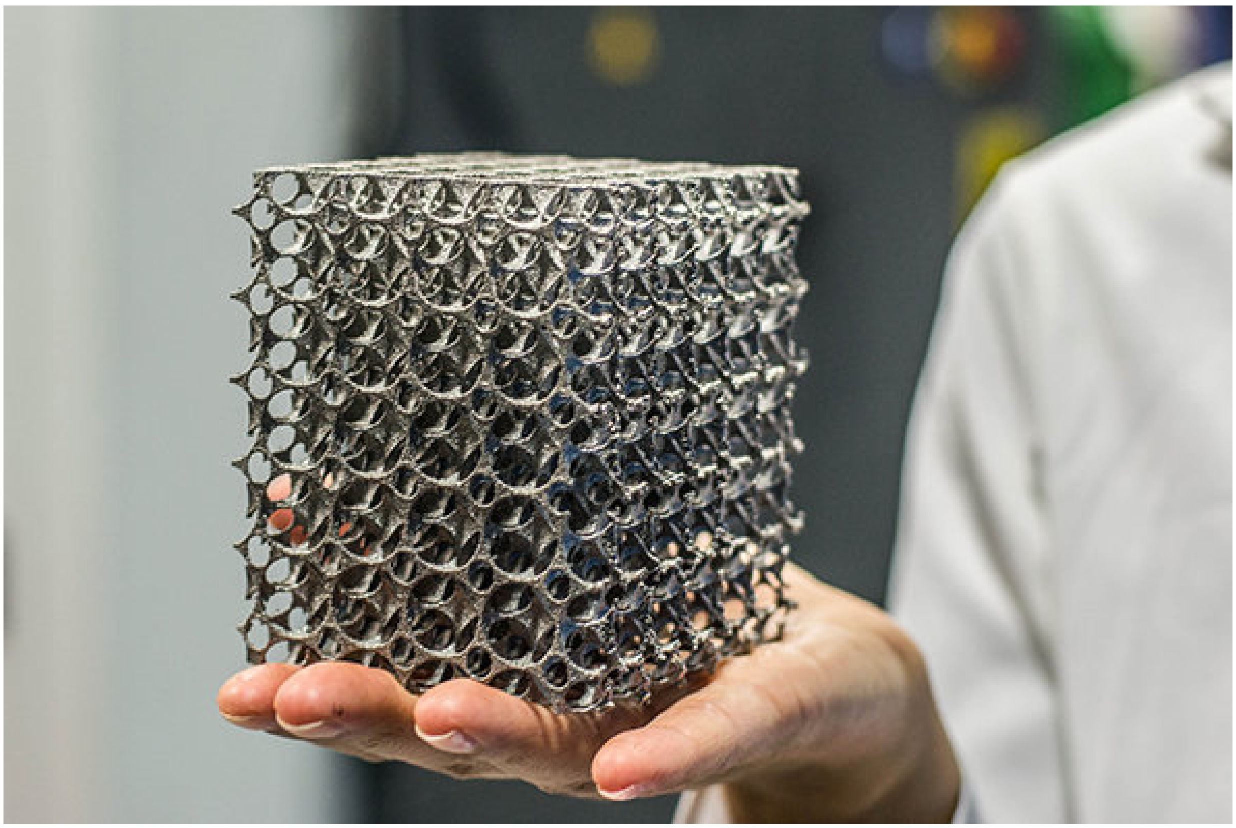

Additive manufacturing makes it possible to create objects with complex geometries. Credit: MIT Sloan School of Management

Additive manufacturing is the process of creating an object by building it one layer at a time. It is the opposite of subtractive manufacturing, in which an object is created by cutting away at a solid block of material until the final product is complete.

Technically, additive manufacturing can refer to any process where a product is created by building something up, such as molding, but it typically refers to 3-D printing.

Additive manufacturing was first used to develop prototypes in the 1980s—these objects were not usually functional. This process was known as rapid prototyping because it allowed people to create a scale model of the final object quickly, without the typical setup process and costs involved in creating a prototype.

As additive manufacturing improved, its uses expanded to rapid tooling, which was used to create molds for final products. By the early 2000s, additive manufacturing was being used to create functional products. More recently, companies like Boeing and General Electric have begun using additive manufacturing as integral parts of their business processes.

How it works

To create an object using additive manufacturing, someone must first create a design. This is typically done using computer aided design, or CAD, software, or by taking a scan of the object someone wants to print. Software then translates the design into a layer by layer framework for the additive manufacturing machine to follow. This is sent to the 3-D printer, which begins creating the object immediately. "You go directly from digital to physical, which is quite a change," said MIT Sloan senior lecturer Thomas Roemer, who is the executive director of MIT's Leaders for Global Operations program.

Additive manufacturing uses any number of materials, from polymers, metals, and ceramics to foams, gels, and even biomaterials. "You can use pretty much anything," said Arvind Kalidindi, a materials science and engineering PhD candidate at MIT. "As long as you find a way to locally join two parts, you can 3-D print it."

The actual process of additive manufacturing can be done in a number of ways, all of which can take several hours to several days, depending on the object's size. One common method uses a nozzle to lay successive layers of material on top of each other until the final product is complete.

Another process uses powders, typically made from metal. This works by "filling a bed with powder, and melting the parts of the powder that you want to form a solid part layer by layer. After you do this, all the loose powder falls away from your final part," Kalidindi said. This is usually done using lasers or electron beams, but another technique involves using a polymer to adhere layers of powder together. The part is then placed in a furnace where the plastic melts away and the powders sinter together, forming the final part.

The advantages of additive manufacturing

Additive manufacturing has some distinct benefits. With traditional manufacturing, the entire supply chain can take months and require an investment—sometimes millions or billions of dollars—that can only be recouped by high-volume production. With additive manufacturing, much of the supply chain's intermediate steps are removed. "The speed at which you can get to a single part is much faster," said Roemer, since people can send a design directly from their computer to the 3-D printer.

Manufacturing something additively also makes it possible to create objects with functionally-graded materials—meaning they can have different materials on the inside and outside. "Imagine you want something that has high conductivity, but also is abrasion resistant," said Roemer. "On the outside, you have the abrasion-resistant materials, like ceramics, and on the inside, you have the conductive materials, like metals. Creating something like that is quite difficult to do with conventional manufacturing."

Roemer believes, though, that the two biggest advantages to additive manufacturing are creating complex geometries and producing small lot sizes.

"With additive manufacturing, you produce—layer by layer—pretty much any geometry you want to create. You can create 3-D entities that are much more complex and have different material properties," said Roemer. With subtractive manufacturing, some objects are too small or have too awkward an angle to subtract materials in the desired way. Additive manufacturing eliminates that barrier. This also means that manufacturers can eliminate weight from an object. This is particular important in the aerospace and automobile industries, where weight can affect the functionality of a final product.

Additive manufacturing also makes it easier to create small amounts of something. With traditional manufacturing, setup costs mean producing small lots is not cost effective. But with additive manufacturing, setup costs are mostly eliminated, so creating just a handful of objects becomes more reasonable. This makes customizing products, like prosthetics or implants, easier, and could result in better outcomes for patients. Hearing aids, which are customized for each person, are almost entirely additively manufactured.

Issues with additive manufacturing

Additive manufacturing has its share of challenges, too. Additive manufacturing machines are expensive, sometimes hundreds of thousands of dollars. Using them to create large lot sizes takes longer than with traditional manufacturing. And many objects that are additively manufactured require some post-processing to clean and smooth out rough edges, among other things.

One of the biggest challenges, though, according to Kalidindi, "is making sure that your final part has good properties. From a material science perspective, that is probably the biggest challenge of additive manufacturing. How do you reduce the number of defects that could form?"

Kalidindi, who researches the chemistry of metal powders, says the metal, its properties, and the process used to create the object can all have an effect. "If powders don't quite sinter together, it forms defects that lead to failure," Kalidindi said. "You can get residual stress based on how you process your metal, and there can be some internal strain on the material that can lead to the part wanting to naturally bend."

Defects in additively manufactured objects is not unique to metals. Given the relative newness of additive manufacturing, researchers are still trying to understand the many different aspects of it, how the materials work together, and how to decrease the likelihood of defects in final parts.

Additive manufacturing versus conventional manufacturing

Despite all the advantages of additive manufacturing, "I don't see traditional manufacturing being replaced," said Roemer.

That is because, aside from specific use cases, traditional manufacturing is still faster and less expensive. This is especially true when creating granular products. The smaller the layer size, the slower the manufacturing. While the initial units are cheaper and faster when made with additive manufacturing, in the long run, printing out every unit would take longer.

For some companies, though, using additive manufacturing is worth it. Right now, "whenever we see small lot sizes and high demand for functionality, that's the sweet spot for additive manufacturing," Roemer said.

A low-cost 3-D printed prosthetic hand. Credit: M.R.Nuckels via Wikimedia

Roemer believes there is a case to be made for a hybrid model of manufacturing. In this situation, the initial products would be additively manufactured, but traditional manufacturing would take over once the lot sizes increased to a certain point. That would continue while the product was in high demand, but instead of creating large amounts of excess inventory, companies could revert back to additive manufacturing to meet demand as needed once it slowed.

This end of product-life use of additive manufacturing could be useful even for companies that have never used the technology before, said Roemer. Companies like Caterpillar, which ships replacement parts within 24 hours, could have 3-D printers set up at strategic locations to print and deliver those parts instead of keeping inventory stocked at those locations. Mercedes, which says it will always supply spare parts for any car, could 3-D print the parts for a 1928 SSK for significantly less than it would cost to produce them traditionally.

Possible industries for disruption

There are a few industries where 3-D printing parts or products makes more sense than manufacturing them traditionally. Aerospace, racecars, and the medical field are all industries where additive manufacturing can make inroads.

That is because they are all industries where function is more important than price. Or where small lot sizes or customization makes it less expensive to manufacture an object additively than traditionally.

Many other businesses may have uses for additive manufacturing. According to Roemer, without the setup costs of creating a new product, entrepreneurs can quickly additively manufacture objects or parts to see if they work as needed. If they don't, they can iterate and try again, all using an additive manufacturing machine, until they find a product that does. They may not even need their own machine to do this—companies like UPS have set up 3-D printing machines at various locations that can be used by anyone.

Established businesses can also evaluate whether additive manufacturing can be part of their business models. If a company produces products that are specialized or would benefit from the ability to have complex geometries, it will have to determine whether additive manufacturing would improve its products. Companies like Adidas are using additive manufacturing to create sneaker soles at speeds that may make it suitable for mass customization.

4-D printing and other applications

With typical additive manufacturing, machines build a 3-D object that is fixed. 4-D printing creates 3-D objects that have the ability to change or transform over time, without human interaction.

There are several applications for 4-D printing. One is extreme environments, such as space, where self-configuring materials would be useful. Another is biomaterials, that would continue to evolve over time.

Other uses of additive manufacturing will continue to present themselves—some companies are already experimenting with additive manufacturing to make everything from houses to food—especially as costs come down and the actual manufacturing speeds up. In the meantime, industry leaders are not the only ones interested in additive manufacturing developments; a community of hobbyists has emerged, as well. While commercial additive manufacturing machines can be large and expensive, 3-D printing companies are increasingly making smaller, desktop-sized 3-D printers that hobbyists can buy for only a few hundred to a few thousand dollars.

More information: Felix Lederle et al. Improved mechanical properties of 3D-printed parts by fused deposition modeling processed under the exclusion of oxygen, *Progress in Additive Manufacturing* (2016). DOI: 10.1007/s40964-016-0010-y