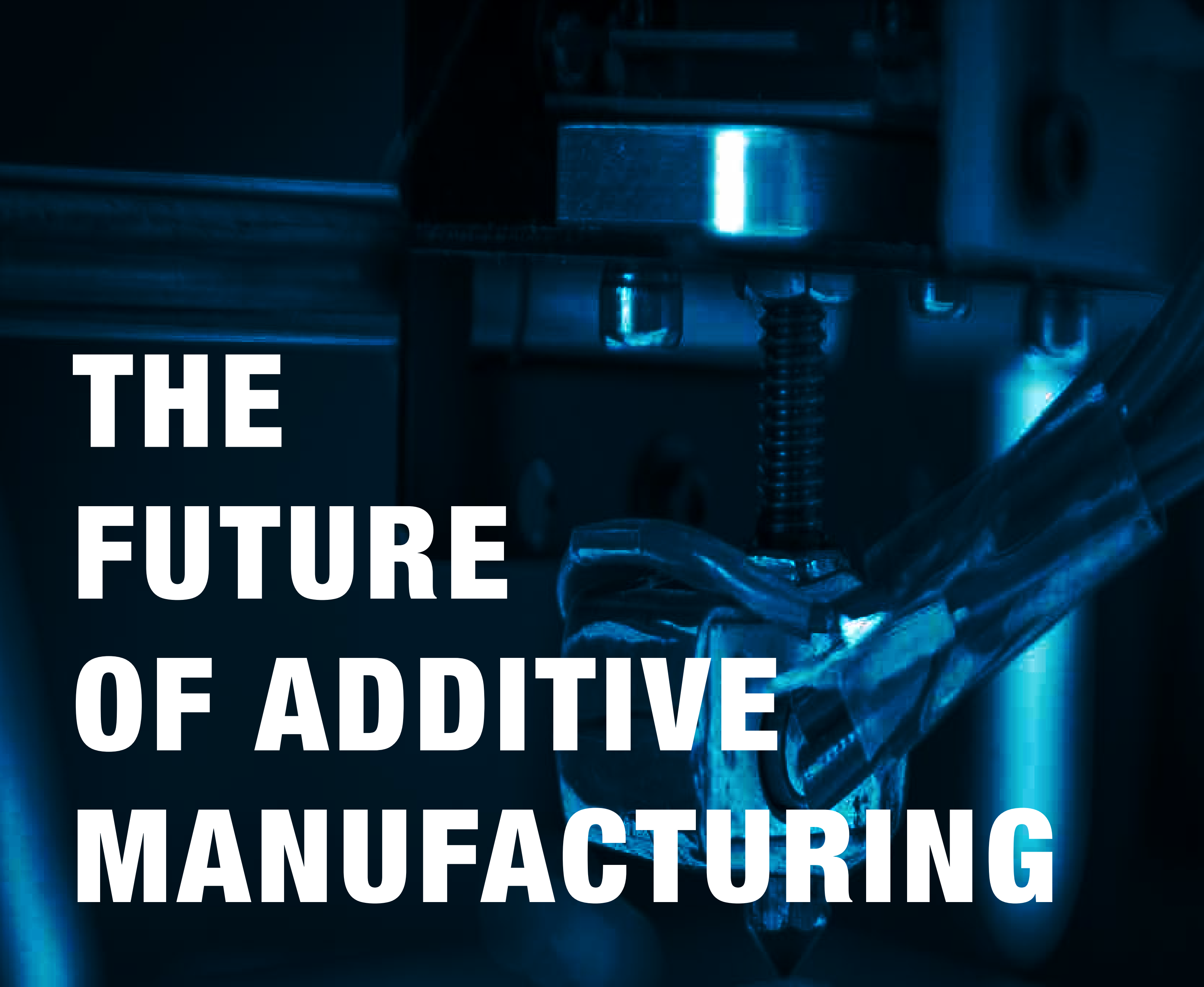


THE FUTURE OF ADDITIVE MANUFACTURING

In Additive Manufacturing (AM), a variety of different techniques essentially combine planar layers of material, sequentially to form a 3-dimensional solid object. Following the initial introduction of the key technologies, development of AM has been mostly incremental. The earliest machines included photopolymer curing, powder sintering, filament extrusion and sheet lamination. All of these technologies still exist today, with a few additions. Its continued use has seen this technology, which was primarily aimed at producing prototyping models, develop to include tooling and direct manufacture of consumer products.

All of the current commercial technologies have seen improvements in speed, part accuracy and material properties. Increasing interest and application from industry has subsequently led to reductions in machine and operating costs as well as an increase in the range of applications. Legitimisation of the industry is evidenced by the development of international standards. Further, recognition of the widening appeal of this technology has led to regular use of the term 3D printing by the general public at large.

It may be good to take a look at the current status of the technology and affected industries by addressing the following questions:

- What industries are likely to use the technologies in the future and why?
- What new materials are we likely to see in the future?
- How will we incorporate the technological advances that AM can provide at the design stage?

AM industry and applications

Fundamentally, AM technology has hardly changed in recent years. Having said that, there have been dramatic improvements in existing technology that justifies the transition from prototype production to manufacturing. This transition is a culmination of a number of evolutionary developments in materials and processes combined with the reduction in costs of the technology that has served to open it up to a wider user base. However, there has also been a change in the mind-set of users that has opened their eyes to new applications.

Development of AM technology over the years has been exemplified by three key industries for differing reasons:

Automotive manufacturers exploited the technology to help new products get to the market quicker and in a predictable manner. Small savings in time and development costs can result in significant overall savings in vehicle development. An example approach is the use of AM for small batch production before full production tooling is ready. Manufacturers of high-end, low-volume automobiles are even using AM as a preferred production process because it is the most cost-effective approach to use.

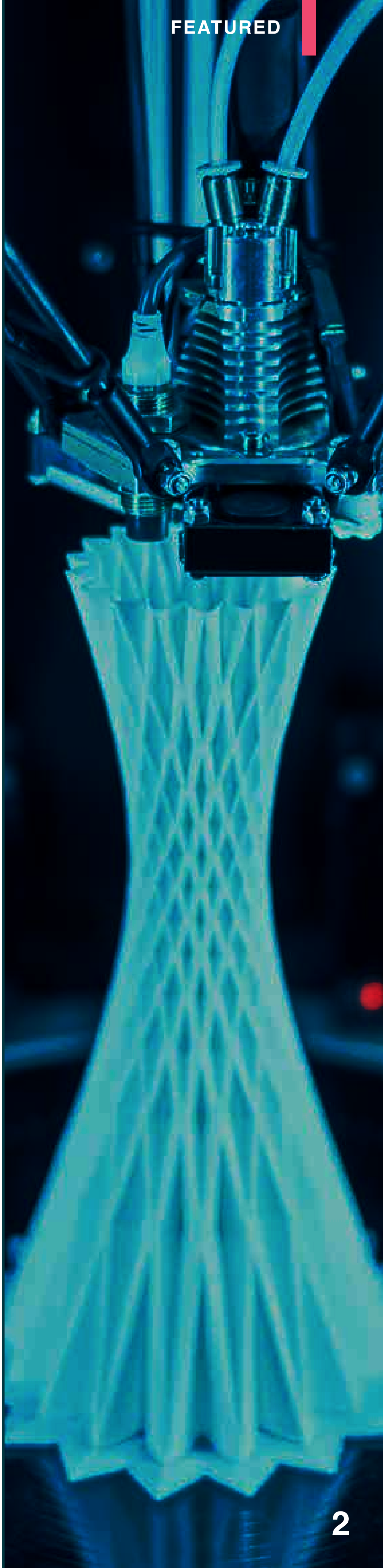
Aerospace companies are interested in AM's ability to integrate mechanical functionality, reduce component counts, create internal functionality and reduce weight. Whilst there is already a flourishing industry for making polymer parts on high-performance military aircraft, probably the greatest interest in this industry is for direct metal fabrication.

Medical industries are particularly interested in AM technology because of the ease in which 3D medical imaging data can be converted into solid objects. In this way devices can be customised to suit the needs of an individual patient. This has not taken off quite as quickly as expected however, possibly due to it being a highly regulated and risk-averse industry. Where there has been opportunity for large-scale customisation (like in dentistry and for in-the-ear hearing aids) then there has been good reward.

The major limitations to AM are speed, accuracy, nonlinearity, material properties and system cost. All of these are being addressed by machine vendors. System cost is a very subjective topic however and machines sell at a particular price partly because of their perceived value to users. If the manufacturing costs can be reduced, or the number of potential users becomes larger, then system prices will fall. There is an increasing number of low-cost systems available due to an ever-increasing competitive market. Most machines are based on melt extrusion technology since the designs are generally available and the process is easiest to synthesise. However, we can expect more powder-based and droplet-based technologies to become available in the years to come as large-scale materials suppliers and mainstream manufacturers decide the market is sufficient to accommodate the high capital costs of mass-manufacture of AM machines.

Increased use of AM technology inevitably means finding its way into more application areas. Some of these areas are very performance or safety critical, requiring careful process control and tracking to ensure high quality. Acceptance will be much easier if suitable standards are in place. Continued implementation of ASTM, ISO and other international standards will certainly assist this acceptance.

So what is the future for AM technology, beyond incremental developments that will influence new manufacturing applications?



A few predictions:

- As fabrication speed is significantly increased, parts will become available in minutes (even seconds) rather than hours. Consumers would be prepared to wait this short time for their parts to be made over the counter. Machines are likely to be seen in shopping malls and other locations where consumer parts can be made to order.

- AM can be used in conjunction with other manufacturing processes that can also be automated. Future manufacturing equipment may be designed to incorporate AM. High performance industries like Aerospace manufacturing will be the first to take advantage of this due to obvious performance gains. These hybrid additive/subtractive/formative/assembly technologies will not be as versatile as current AM machines; more likely specifically designed for particular sizes and types of product, like turbine blades or wing struts.

- An increasing number of AM systems have already demonstrated multiple material capability. We will see many more machines exploiting this capability in the future since this is not only a relatively straightforward thing to achieve with a number of the technologies, it also will result in products that may have been extremely difficult to manufacture using conventional technology.

- A new application area that is developing quickly is tissue engineering, where AM is used to generate structures that will result in biocompatible medical implants. These implants will contain cells to form human tissue inside the body.

AM Materials

From the very beginning materials engineering has been an important driving force for AM development. Like traditional manufacturing processes, the initial choice of material was tied to the process constraints. For example, photosensitive resins must be used for vat photopolymerisation AM. Improvement in intrinsic properties of AM parts can be engendered through improvements in base materials. With increased demand comes a fiscal motivation to tailor and optimise materials for best results. Examples are new formulations of photopolymer resins, development of polyamides specifically for powder-bed fusion, and the roll-out of new composite melt-extrusion materials. Of particular interest are the increasing array of metallic materials and advanced engineering polymers like PEEK and PEKK becoming available.

Application development using AM parts can be seen in so-called “conversion technologies”. Here, AM part geometry is maintained whilst a different material is substituted for the as-processed material. Examples include using AM binder methods which are burnt away to create uniformly shrunk ceramic or metal parts using a follow-up furnace stage. Further, creation of low-ash AM materials can be used to create parts that will eventually be sacrificed during a casting stage.

As AM moves into direct competition with traditional manufacturing for service parts, the need arises to match service properties. For some systems, post-processing was straightforward and comparable to traditional manufacturing.

The markets for AM have grown to a stage now that the technology is getting the attention of major materials suppliers. It is anticipated that once these major producers are convinced that the time is right, one would expect to see new materials with improved manufacturability and service properties to enter the market. Increased competition will drive down costs, which will be welcomed by both parts providers and consumers.

Design for AM

The term "design", in regard to AM, can cover several aspects. These include industrial design, mechanical engineering design, architectural design and fashion design. AM impacts all of these areas by enabling manufacture of designs that were previously uneconomical or even impossible. Examples of these designs are increasingly finding their way into the mainstream use, particularly as online consumer products. There are a few reasons why using AM is desirable such products:

- Custom-fitting to suit individual ergonomic requirements.
- Improved functionality of the product performance through adoption of complex forms, both externally and internally.
- Reduction of overall part count in a product by producing a lower number of (usually) more complicated parts.
- A desire to endow the product with specific design features that will increase its value to the customer.

Those familiar with product design will recognise that a particular design feature is capable of addressing more than one of these desires, e.g. a weight saving functional structure may also produce a dramatic aesthetic form. The implications upon design using AM are twofold. First, computer aided design software must be upgraded to handle the unique characteristics of parts designed for AM. For example, the ability to represent several materials or colours in the same model, the ability to have a gradual change from one material to another, the ability to assign a particular surface texture or pattern to a part and the ability to generate and represent complex internal structures. Many of these issues are now beginning to find their way into commercial software.

Another implication relates to designers, namely, how can they take advantage of all the opportunities that AM offers? Partly, this is a matter of education. Designers need to be made aware of the unique features of AM and encouraged to ignore the "design for manufacturing" limitations they have been used to.

There is a need for increased creativity and it could be argued that the ultimate limitation to the shapes created by AM will be the imagination of the designer. Designers, of all disciplines, must unleash their creativity to come up with product, building and fashion designs that would previously have been implausible. In essence, how are we going to get designers to think what was unthinkable in the past?

This poses a problem to designers who are expected to produce something both functional and aesthetically pleasing. Our education systems tend to produce designers who are capable of either one or the other. AM, on the other hand is uniquely capable of producing something which is both, without the need for compromise. We need "hybrid" designers who are capable of taking inspiration from nature, fashion or the built environment and then converting these into product forms that will also perform efficiently and ergonomically. Such designers already exist but for AM to reach its full potential we need them to be the norm rather than the exception.

So what might the future of design for AM be?

If the technical and human issues can be addressed, then a unique hybrid of the aesthetic and functional design disciplines might emerge. Going back to the dual purpose feature mentioned earlier, a single designer may take inspiration from nature, with calculations from software, to create visually stunning, weight- saving designs that can only be realisable using AM. Indeed, if the concept of beauty could be programmed into the software, then that hybrid designer might actually turn out to be a computer rather than a person! ■