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Factories of the future

Additive manufacturing and the emergence of 4D printing

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ADDITIVE MANUFACTURING

Additive Manufacturing (AM), popularly known as 3D printing, enables the creation of complex 3D geometries not possible with traditional manufacturing, through the localised deposition of material in sequential layers. It can be defined through its dramatic difference from conventional manufacturing techniques such as machining, casting, and forging; whereby products are formed layer-by-layer as matter is repetitively built up rather than removed.

AM is a form of Digital Manufacturing; it is an automated production process enabling digital designs to be transformed into physical, tangible objects. The digital nature of AM will lower the dependence of current factory floors on highly skilled and experienced workforces. Instead, future factories will take an integrated approach to manufacturing centred around a computer system. This has led many researchers and policy makers to prophesise the innovative force of AM and identify it as a key enabler for Industry 4.0.

In 2016 the AM market was worth $6.06 billion, growing from about $0.4 billion in 1996. This is forecasted to grow to $26.2 billion by 2022 [1]. Whilst the value of additive manufacturing is mostly from industrial applications this still only represents 0.05% of global manufacturing, suggesting that growth in industrial areas will continue at pace.

INDUSTRY BENEFITS

AM has numerous benefits for industry, including;

- Increased design freedom: fewer design constraints imposed by the manufacturing technology, compared to traditional subtractive or formative manufacturing processes.
- Greater material control: material is fused together at a local scale (>1 mm spot size) compared to global techniques such as casting. Varying the local build parameters (energy, speed, cooling rate) gives rise to larger material variability both locally (grain structure) and globally (mechanical properties, porosity, structure).
- Component consolidation: is a process in which multiple discrete parts are designed and fabricated together into a single part, thus reducing the number of fabricated parts and the need to join those parts together. This not only reduces the number of parts but shortens assembly lines, certification and inventories.

- Shorter lead times: AM reduces the number of steps in a production chain as there is no need for tool or jig changes, thus reducing manufacturing times. In addition, a product design phase can become more efficient as prototyping is easier, allowing for more iterations or quicker entry to build phases.
- At source production: fewer tools and machining steps are required, so factory chains can become smaller. Reducing the reliance on global manufacturing hubs and redistributing factories into a more localised model.
- Functionalised parts: by creating materials with anisotropic mechanical properties through altering the external geometry, internal geometry or local crystalline structure functional properties can be embed into parts. Mechanical properties such as stiffness, flex and density can be controlled.

THE IMPACT ADDITIVE MANUFACTURING COULD HAVE ON YOUR BUSINESS

In many cases AM is a far less expensive method to produce a prototype than traditional manufacturing. Today, the speed and convenience of AM allows firms, small and large, to be more nimble and to produce and test different versions of a product overnight. A rejected prototype no longer costs a lot of money or time, and becomes a creative part of experimentation processes and research and development. By employing in-house, cost effective, AM techniques designers can enter a multiple design-and-build cycle earlier allowing for more iterations and a better design outcome.

In addition, AM is likely to help companies to move towards a more adaptive and flexible business model. Companies employing traditional manufacturing techniques may find themselves stuck within their own model/market sector due to the limitation in the production line set-up or their design portfolio, and the cost of altering these. The adoption of AM could enable companies to rapidly test new ideas, creating a more robust company, able to withstand market changes, within its own market sector by increasing its design portfolio at little expenses. Simultaneously, companies are able to move into neighbouring market sectors, allowing them to try out various business models at little cost.

A NEW FRONTIER: 4D PRINTING

A new and exciting area of AM that has recently emerged is the concept of 4D printing. Here AM technologies are used to print objects that can alter their shape over time, hence an additional 4th dimension. Printed objects can be programmed to move in specific ways so that predetermined motion can be achieved and a whole range of functions carried out. Benefits of 4D Printing are that printed objects do not have a permanent shape, colour, function or other characteristics. While 3D Printing is used to transform digital data into static objects, 4D printing provides an additional programmability and transformability in 3D printed objects.

The ability to create smart, programmable, objects that can self-actuate has created a lot of excitement within industrial sectors. Much of this interest is related to the effect 4D printing has on build times, assembly times, maintenance protocols, improvements to performance and, ultimately, cost reduction.

THE IMPACT OF 4D PRINTING

To understand the full potential impact that this technology can have on our lives and on industry, let's start by considering products and structures that we encounter everyday. As engineers and designers we are very good at creating products that perform a multitude of functions. Many of these products are made from multiple components that are assembled in manufacturing. In construction we can build a skyscraper in about two to three years. The building itself will consist of nearly a million parts when finished, all assembled together to perform various functions ranging from structural to aesthetic. An aeroplane takes around 80 days and consists of roughly six million parts. A car takes around one day with about 30,000 parts.

We are very successful at these manufacturing processes but it does come with some draw backs: often these products are complex things, constructed from complex parts, which come together in complex ways. This creates major inefficiencies, high energy consumption and excessive labour techniques, in terms of both manufacture and operation.

What if we could dramatically reduce the need for complex systems made from so many parts? What if we could create structures that self-assemble on demand, significantly reducing construction times? What if we could create objects that change their shape intelligently, in a pre-programmed manner or in response to their environment?

CURRENT AND FUTURE APPLICATIONS OF 4D PRINTING

4D printing has been used to create delightful motion in sculptures and artefacts but we are now nearing the point where we can employ 4D printing in commercial applications such as deployable structures used in consumer goods, for example flat pack furniture, or clothes and trainers that react to their environment to improve comfort. Moving forward we can imagine building facades that react to the weather to regulate building temperatures, or deployable buildings to be used in high-risk zones.

There are many benefits for 4D printing in the healthcare sector. Imagine implants that don't require evasive, time consuming, hazardous surgical procedures but instead can be done quickly and easily, with parts that are easily inserted and self-construct. You could simply swallow a piece of equipment that is then stimulated into action, and morphs into the required shape.

Imagine an aeroplane wing with no hydraulic rams, no oil pipes and no machine elements; just a single, responsive surface that can be tuned to the optimal aerodynamic shape whilst in-flight. Alternatively consider locations where construction is difficult, dangerous and expensive, for example space, where the ability to launch self-assembling structures into these could dramatically improve space exploration.

WHAT DO I NEED TO START 4D PRINTING?

One way to create products with shape shifting behaviour is through the use of smart materials. These are designed materials that have one or more properties that can be significantly changed in a controlled fashion by an external stimulus. Nearly all materials have the characteristic of reacting to stimuli in some way (e.g. thermal expansion), but this reaction does not mean the material is 'smart'. If a material can react in a reliable, repeatable and useful manner, then it is called a smart material. Compared to ordinary materials, smart materials can be programmed and customised by purpose, and specific functions can be embedded. The requirement of additional processes or components can be minimised, which can be a huge benefit for industries.

A commonly used smart material is shape memory polymers. A shape memory polymer is a polymeric material that can significantly change shape in a controlled manner once triggered by external stimuli. The stimulus can range from inputs such as heat, UV and magnetic fields. 3D printing with polymers is widely available and the most common material of choice. However, the availability of shape memory polymer for 3D printing is somewhat lagging.

Once you have sourced your shape memory polymer and identified an appropriate AM technology, you need to create your product design. It is important to take full advantage of AM and consolidate components together, embedding functionality into the part such as living hinges and springs. Once printed the part is in a 'programmed' state; this is the shape the part will remember. By heating the part up into a rubbery state, the object can be manipulated into a 'temporary' state. The object will hold this form until triggered by an external stimulus and returns to its original programmed state.

In the design phase it is important to consider the desired shape change; is this a simple movement (translation of a single part) or complex (folding of multiple parts)? Do you want all the shape change to occur simultaneously or sequentially? You need to consider potential collisions that may cause your desired shape change to fail. A benefit of AM is that you can quickly move from CAD design to physical prototyping and testing of your design. This will help identify any errors quickly, at low cost, allowing you to alter your design until a solution is found.

CONTROL OF SHAPE SHIFTING BEHAVIOUR

There are three methods of shape memory behaviour control. These will control how long your object requires stimuli before shape changing begins and how quickly, once triggered, it morphs from its temporary state to its programmed state. These are;

1. Altering the chemistry/type of material you employ,
2. Changing the global dimensions (size, thickness etc) of your object,
3. Changing the internal structure of your part (creating voids).

The final method is only achievable through AM. As the part is built up layer by layer, the internal volume is accessible. Here, infill structures can be created that are placed specifically to control the shape changing behaviour. This is extremely beneficial as it offers a form of shape-change without compromising on the external geometry, something that might be a design constraint. In addition, there are few smart materials available and their development is expensive; large material development laboratories are required. Altering dimensional parameters is therefore often preferential.

FUTURE CHALLENGES AND OPPORTUNITIES

When considering AM as a viable manufacturing option for your product it is important to find the ‘value added’; what is it that AM provides for your specific needs that adds value compared to traditional manufacturing systems? This could be during the design phase as a rapid prototyping aid to improve design development, or to take advantage of increased geometric freedom. It could also add value in the build phase, for example through reduced tooling costs, or in the post-build phase by using AM to create legacy services and digital inventory systems. For many businesses AM is having a positive, disruptive impact on design, manufacture, company location and business models.

In addition, AM creates significant opportunities for co-creation between firms and their customers. Co-creation and mass-customisation are two key drivers for user innovation, which is itself a critical source of radical innovation. These opportunities are born from AM’s use of digital design and manufacture, namely cloud based packages that aid simultaneous multi-user interface and interaction. It is the combination of design flexibility, speed and cost benefits that makes AM so attractive to designers and industry.

Before large scale take-up of 4D printing can occur some challenges remain unanswered; from material preparation (base materials required for 3D printing) to manufacture (3D printing technologies capable of using smart materials). Shape memory material technology is still in its infancy, and there are a number of barriers preventing large scale adoption, including a limited material library, material availability and high material costs. Currently there are few 4D printed components commercially in use, however this is likely to change in the next few years. The ability to create smart, programmable objects that can self-actuate has created a lot of excitement within the robotics, photonics and medical sectors.

AM is a rapidly evolving form of manufacture with new, novel processes and materials appearing continuously. It is set to disrupt factories of the future in their location, layout, capability and usage. AM also offers numerous opportunities to improve manufacturing efficiency through faster design-to-manufacture cycles (rapid prototyping), reduced lead times, reduced assembly complexity, rapid tooling and digital inventories. It offers opportunities for design innovation by radically re-thinking the design of products, parts and components through increased design freedom and build capabilities. 4D printing is a great additional tool in this AM design revolution; with a bit of imagination a truly disruptive product can be created.

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[1]T.T. Wohlers, Wohlers Report 2018: 3D printing and additive manufacturing state of the industry annual worldwide progress report, 2018