TECHNOLOGICAL CHANGE AND INNOVATION SYSTEM OBSERVATORY

TRADE & INDUSTRIAL POLICY STRATEGIES

ADDITIVE MANUFACTURING: 3D AND 4D PRINTING

TECHNOLOGICAL CHANGE AND INNOVATION SYSTEM OBSERVATORY

The aim of the Technological Change and Innovation System Observatory project is to support the Department of Trade, Industry and Competition (the dtic) and industry sectors to develop an integrated, strategic response to discontinuous technological change and disruptive innovation. It aims to equip public and private organisations to become more sensitive to global technological shifts, and the changing demands placed on the innovation system, the manufacturing sector and its stakeholders.

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Additive layer manufacturing describes a manufacturing process in which a digitally controlled head with a laser deposits a fine layer of raw material to construct a three-dimensional object. Additive manufacturing is sometimes also called 3D printing.

3D desktop printers are already available to consumers at computer retailers and hobby shops. The performance and functionality of desktop 3D printers are increasing rapidly, while the cost of ownership is falling rapidly. Desktop 3D printers usually deposit a layer of molten plastic on a bed to create a three-dimensional shape.

In the industrial domain, rapid advances are being made in the melting of metals, alloys, high performance plastics and polycarbonates using lasers. Likewise, in the medical field, different technologies are being developed that allow for the combination of cells, growth factors, biomaterials and tissue to grow organs. Additive manufacturing technologies are also used to print complex sand moulds, or to create wax moulds for investment castings. The metal objects made by 3D printed moulds are basically ready-for-use and require almost no further grinding or processing.

Some of the precision control elements from the 3D printing domain are also being taken up in other domains, such as food preparation and architecture.

4D printing is the process whereby a 3D printed object transforms itself over time into another structure after being triggered by heat, energy, moisture, wind or other forms of energy. This field is moving from research laboratories to commercial development, with applications in construction, space technology and new materials science.

TECHNOLOGICAL NOVELTY OR MERIT

Additive manufacturing is different from conventional fabrication in that it does not start with a solid material that is then machined or reduced to another form. It starts with a digital design file that is converted to a layered instruction file. This file instructs a "printer" that positions a printhead that deposits materials with great precision. In the case of laser sintering, a laser is directed to melt a deposited material such as titanium, steel or other alloys. With 3D printing it is possible to create unique shapes that are almost Impossible or expensive to fabricate using conventional manufacturing processes. It allows design engineers to create components that are stronger and lighter than what is possible through conventional fabrication processes.

While additive manufacturing is often associated with rapid prototyping or creating highly detailed models, it is increasingly used to manufacture final components, implants or intricate shapes that requires limited or no machining. Additive manufacturing is also disrupting other manufacturing functions, such as tool and mould making.

NEW COMPETENCE REQUIREMENTS

Skills and knowledge

Additive manufacturing requires the close integration of digital design and engineering skills. It is clumsy to substitute a design that can be fabricated in a conventional way with an expensive 3D printer. To harness the flexibility, accuracy and capabilities of 3D printers many products, components, and manufacturing process must be redesigned and re-engineered. Furthermore, even if it uses known alloys, the properties of a laser sintered/melted component are different from a component that was cast, forged or extruded. It is therefore not a simple substitution for current fabrication processes.

For critical components, software simulation such as finite element analysis is needed to ensure that the 3D printed components comply with performance and safety specifications. When 3D printers are used to create sand moulds (for metal casting), it is important that software simulation is used to make sure that gases can escape the mould and that the properties of the manufactured products are within specifications.

Larger additive manufacturing systems require engineers to operate and maintain them.

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Additive manufacturing brings products and component design much closer to the process design. It will make many functions redundant, such as certain fabrication roles, quality control, tool, mould and die making, and some downstream polishing and finishing jobs.

Organisational arrangements

Additive manufacturing is more precise, but it requires precision in the whole value chain from raw material procurement, product design, simulation, the manufacturing environment, and even in packaging and shipping.

3D printing dramatically shortens the duration of design to production iterations. It requires a much closer integration between design and manufacturing. In essence, the quality control function is shifted from the production and post-production process to the design office.

For quality control, design integration and performance, much closer collaboration between the product designer and the client or the manufacturers of other components will be required. An example from the medical field is when design engineers work closely with surgeons to design implants that needs to consider where nerves and arteries run.

In larger additive manufacturing machines, the marginal cost of adding more components to the volume of the machine is basically limited to the cost of additional materials. This means that for organisations with sufficient volumes of components, the marginal cost for each component is reduced. However, the co-ordination effort to fill the print bed is then increased.

Value chain effects

From a raw materials perspective, additive manufacturing platforms are sensitive to the quality and consistency of its feedstock. For instance, a metal casting foundry that wants to introduce additive manufacturing mould printing would have to switch from using silica sand to finely grained sand that is more expensive (and most likely imported). Metal foundries that in the past relied on melting scrap metal would have to switch to procuring carefully manufactured metal compounds, resins and new alloys.

An area of rapid development at present is the creation of new feedstock manufacturing processes, such as titanium powder or other alloys or new materials.

The design software will most likely need to be compatible with the software used by the manufacturers of complimentary or related components, and not all design applications can reliably export to the required file formats used to instruct the 3D printers.

In some value chains, a manufacturer may choose to place its 3D printer near an assembly line of an original equipment manufacturer (OEM).

In the medical field, the 3D printer may be based near a hospital, or the design engineers would have to be close to the surgeons. Due to the requirements of engineers and complementary knowledge skills, 3D printing operations may be closer to the design office or the market than a conventional factory. As 3D printing reduces the reliance on low-cost workers or cheap land, operations may shift closer to design centres or markets.

MARKET NOVELTY AND NEW FUNCTIONS

Additive manufacturing in all its forms allows for completely new designs of components, products and processes that saves material, saves time and allows for more flexibility. It shortens the design of a manufacturing process and is ideal for rapid prototyping, short production runs and has highly customised solutions.

Additive manufacturing is making in-roads in customised design arenas in the medical sector, in the metals and plastics manufacturing sector, in aircraft, and in the architectural design environment. It both reduces the cost and increases the speed with which a precise design can be created, often requiring limited or now assembly or finishing.

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STRATEGIC IMPACT ON FIRMS

Additive manufacturing impact on firms:

- It benefits enterprises that can translate a bespoke requirement from a client, surgeon or a manufacturer into a digital design. Once the design is approved, the file can then be sent to one or several printers to be printed into a final object. This object may require hardly any fabrication and can be shipped or used in an assembly process immediately. In prototyping environments, different variations of the same design can be created concurrently allowing for performance comparisons to take place between alternate designs. In a metal foundry, different variations of a sand mould can be printed to allow for the performance of different cast components to be compared.
- It brings market development, engineering design and manufacturing much closer and enables flexibility combined with high accuracy.

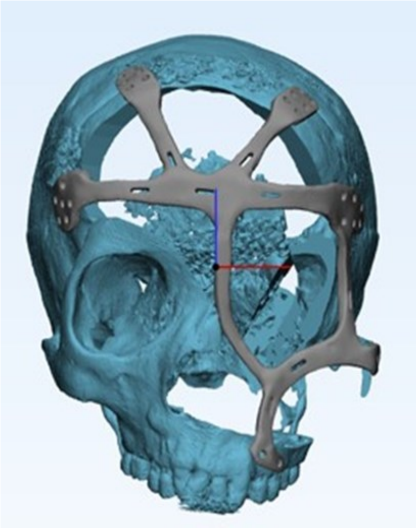
For OEMs that integrate many different components and subsystems into a final assembled system, 3D printed components ensure much better accuracy and hence integration of different system elements.

REGULATORY REQUIREMENTS

There are no apparent regulations that make the dissemination or uptake of additive manufacturing more difficult.

Investors in the equipment typically complain of complicated customs processes and the challenges with importing expensive capital equipment. The delays in clearing imported raw material or components remains a challenge.

In the medical and aerospace sectors, there are regulations that components and implants must comply with. The costs of adequate accreditation in the medical field are high. For aerospace and automotive components, the costs of testing against specifications are extremely high.



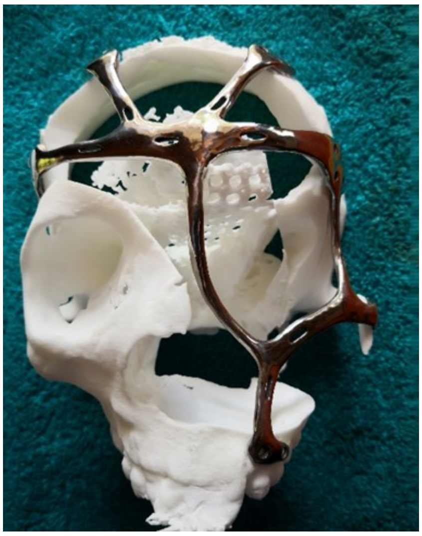


Figure (top): Centre for Rapid Prototyping and Manufacturing (CRPM) custom-designed titanium implant shown on a screen as part of planning activity between engineers and surgeons. Figure (below): The 3D printed titanium implant manufactured by CRPM and later successfully implanted. The implant is mounted on a plastic printed replica of the patient's bone structure.

South Africa has an established track record in additive manufacturing technology adoption and also in new technology development

TECHNOLOGICAL CAPABILITY IN SOUTH AFRICA

South Africa has an established track record in additive manufacturing technology adoption and also in new technology development.

- In the medical field, CRPM at the Central University of Technology, Free State has applied nylon 3D printing to assist surgeons to plan operations and has manufactured custom-designed medical implants from cobalt-chrome and titanium. The centre is certified to the ISO 13485 standard for medical devices. Alongside CRPM is the Product Development Technology Station assists companies to design products for additive manufacturing processes.
- The National Laser Centre at the Council for Scientific and Industrial Research (CSIR) assisted an aircraft manufacturer (Aerosud) to develop aircraft prototypes and components in titanium. This project included building a custom additive manufacturing platform that could print large components to international specifications (https://www.aeroswift.com).
- The Vaal University of Technology (VUT) is supporting the metal casting industry with sand-printed moulds that enable prototyping. VUT is also hosting a casting simulation network in partnership with Ametex, the South African representative of casting simulation software developer Magma.
- The CSIR operates a pilot plant that manufacturers high-quality titanium powder used in the manufacturing of medical implants and aircraft.
- Additiv Solutions is a start-up company that designs and builds laser sintering platforms. The team behind Additiv Solutions were part of the Aeroswift project supported by the (CSIR) and Aerosud.

There are several resellers of both desktop and more industrial machines in South Africa. Desktop printers are even available at retailers. The emergence of 3D printing bureaus offering design and prototyping services indicates the market place is maturing. Several large manufacturers have already established additive manufacturing capabilities.

The Rapid Product Development Association of South Africa (RAPDAS) is a non-profit organisation that brings together the complete additive manufacturing value chain in South Africa. The RAPDASA website lists several categories of South African additive manufacturing roleplayers including equipment vendors, material suppliers, manufacturing service providers, toolmakers and consulting services. The annual RAPDASA conference brings together equipment vendors, resellers, local and international researchers and leading local users.

Demonstration, technology application and advisory contacts

- Centre for Rapid Prototyping and Manufacturing: http://www.crpm.co.za
- The RAPDASA website is at https://site.rapdasa.org and the membership directory is at https://site.rapdasa.org/members/
- Product Development Technology Station: https://www.cut.ac.za/pdts
- Vaal University Technology Engineering Manufacturing Centre and the Materials and Processing Technology Station, both located at the Southern Gauteng Science and Technology Park.
- Stellenbosch University Technology Centre – Laboratory for Advanced Manufacturing: http://blogs.sun.ac.za/stc/
- The CSIR Laser Centre and the National Additive Manufacturing programmes are hosted at: https://www.csir.co.za/national-programmes.