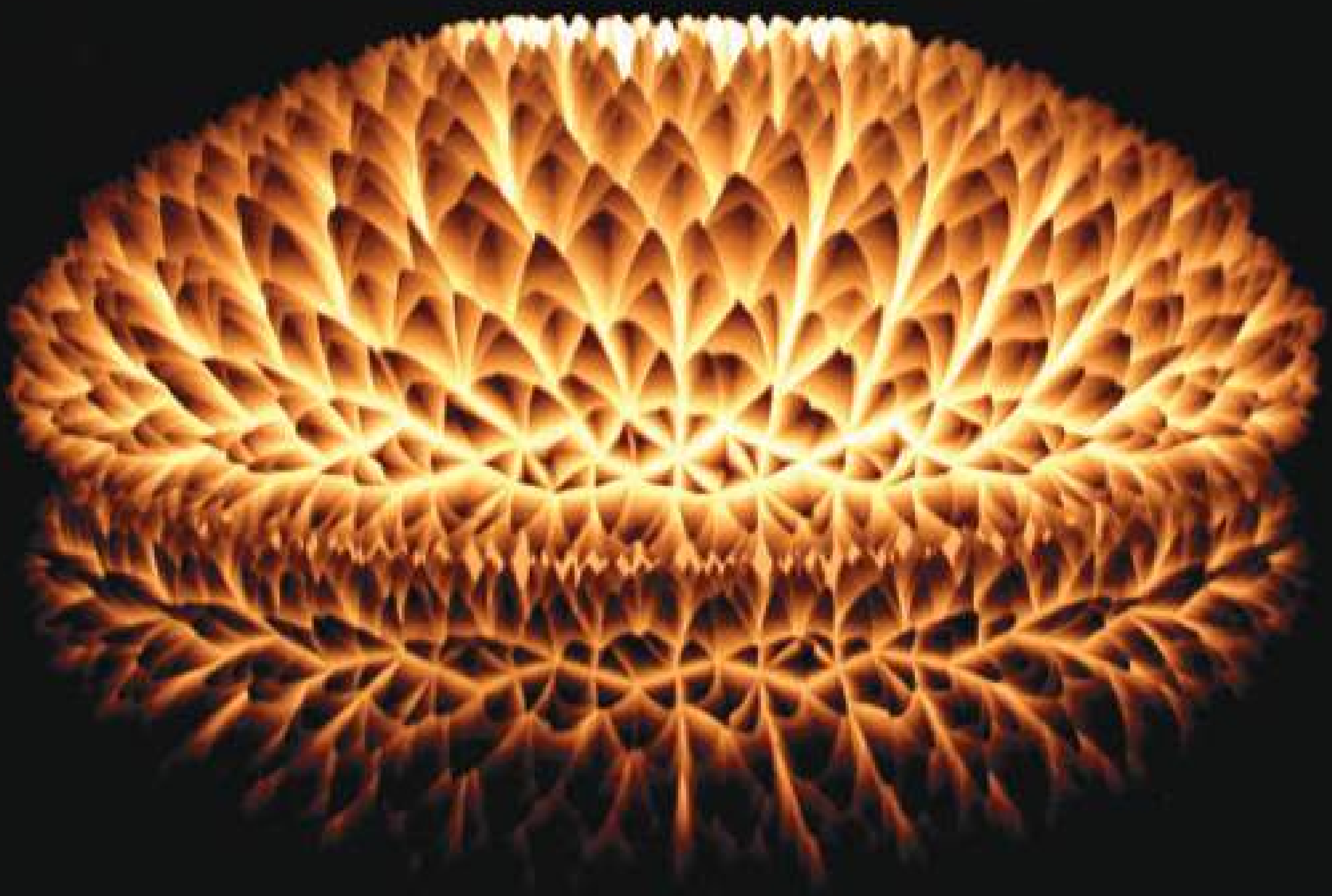
A South African
Additive Manufacturing Strategy



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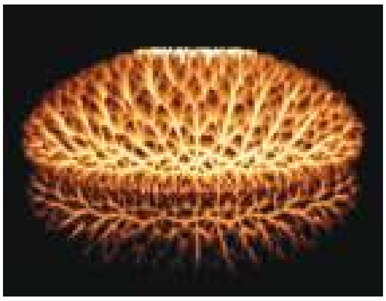

Chrysanthemum centrepiece

Winner of the most beautiful object in South Africa – Design Indaba 2009

Source: Nomili, Michaella Janse van Vuuren

A South African
Additive Manufacturing Strategy

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Foreword by the Minister of Science and Technology

Mrs GNM Pandor

Additive Manufacturing (AM), or 3D printing as it is more colloquially known, continues to capture the public's imagination and inspire innovation in society. Not a week goes by without a magazine article, YouTube video clip or Facebook post on some or other technological breakthrough, novel application or high-tech start-up in this fast-growing and ever-evolving field.

This grouping of 30 years 'young' technologies has in recent years rapidly transitioned from being a curiosity to being used for rapid prototyping and product design to increasingly being a viable niche manufacturing and production technology. Double-digit growth is predicted for AM machine sales and services in the immediate future, indicating that the application of this nascent technology will lead to explosive growth in existing sectors, and also hitherto unknown applications such as bio-printing and integrated electronics.

In 1998, the then Department of Arts, Culture, Science and Technology conducted a National Research and Technology Foresight Project to, amongst other aims, assess the technologies needed for the South African manufacturing industry to become globally competitive. The project highlighted that manufacturers wishing to compete internationally should focus on integrated product development, process and production system design to speed up production time. AM was listed amongst the key technologies that would support this aim.

South Africa began investing in AM technologies in the early 1990s. During the intervening years hundreds of millions of rands of public funds have been invested by various public entities in AM Research, Development and Innovation (RDI) projects and infrastructure. This investment has imbued South Africa with specific world-class capabilities, positioning the country to participate in sub-sectors with high growth potential in AM such as aerospace, medical and dental devices and implants.

AM also holds much potential to improve competitiveness in traditional manufacturing sectors through shorter lead times, tool-less manufacturing, increased part complexity, freedom of design, incorporation of moving parts without assembly, customisation and diverse materials options.

As a disruptive but also enabling technology, AM can support the South African government's objective to grow and diversify the economy via the nine-point plan announced by President Zuma in February 2015. Relevant aspects of this plan for AM are more effective implementation of a higher impact Industrial Policy Action Plan and unlocking the potential of small, medium and micro enterprises, co-operatives, townships and rural enterprises. The AM strategy will therefore support the implementation of national policy such as the National Development Plan and the New Growth Path.

This strategy could not come at a more opportune time. The governments of many advanced economies are investing heavily in AM RDI programmes, often in partnership with the private sector, and South Africa cannot be left behind in this domain. This AM strategy is also a compelling example of how high-tech manufacturing, processes and equipment can unlock manufacturing and entrepreneurial opportunities in rural areas and for new SMEs.

It is therefore crucial for South Africa to invest strategically in AM RDI, skills development and scientific and technological infrastructure to create the industries of tomorrow through next-generation manufacturing methods, and to improve manufacturing competitiveness today through encouraging the adoption of cutting-edge technologies and know-how amongst incumbent industries. It is therefore imperative that actors across the entire National System of Innovation co-invest in the implementation of this AM strategy together with the Department of Science and Technology.

G.N.M. Pandor

Mrs GNM Pandor

Minister of Science and Technology, Republic of South Africa

Executive summary

The Department of Science and Technology (DST) commissioned the development of an Additive Manufacturing Strategy for South Africa. The purpose of this strategy is to identify future addressable market opportunities and products in which additive manufacturing (AM) technology development is required to position South Africa as a competitor in the global market. In this strategy prioritised focus areas are identified and programmes defined that can guide public and private sector investment in AM research, development and innovation (RDI) in South Africa for the period 2014–2023. This strategy was developed through a combination of desk research, international market research, facilitated stakeholder workshops, a survey of local capabilities through meetings and questionnaires, and deliberations within the project core team comprising local experts in AM and technology road mapping approaches.

AM (or 3D printing) is a new, emerging and disruptive manufacturing technology and is generally considered as one of the key technologies for manufacturing in the future. AM brings a number of advantages to the manufacturer compared to the more traditional manufacturing technologies. Complex designs can be manufactured without the need for hard tooling, wastage of material is significantly reduced during the manufacturing process, and time to market can be drastically reduced since AM allows the rapid production of prototypes, tooling as well as final parts.

The growth in AM systems and services globally is impressive. The compound annual growth rate of worldwide revenues produced by all AM products and services over the past 26 years is an impressive 27.3%, with a total market size of $4.1 billion reported in 2014[1]. Wohlers Associates forecasts that the worldwide sale of AM products and services will reach $7.3 billion worldwide by 2016 and will exceed $21 billion by 2020. This is a modest market size considering that global manufacturing market size was estimated at $12.8 trillion in 2014. Predictions, however, become harder if the unknown potential of emerging technologies, such as bio-printing, food, fashion products and integrated electronics, are considered.

The use of AM for the production of final parts is increasing rapidly year-on-year with 42.6% of all applications of AM in 2014 categorised as the manufacturing of final parts. This is up from only 3.9% in 2003. The main applications for AM is in the consumer product and electronics markets, with applications in the automotive and the medical and dental implant market sectors also well established and growing. Internationally, AM is supported through various government-supported initiatives. There are a number of large AM development programmes reported in the United States of America, Europe, the Peoples' Republic of China and Australia.

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[1] *Wohlers Report 2015 – 3D printing and Additive Manufacturing State of the Industry*

In South Africa the uptake of the technology is rapidly growing. The first programmes in South Africa in AM started in the early 1990s with the acquisition of a rapid prototyping system by 3D Systems (Pty) Ltd in 1990 followed by two systems at the Council for Scientific and Industrial Research (CSIR) four years later. Uptake in the technology was initially slow, but since 2011 there has been a rapid escalation in the number of AM or 3D printing systems in the country. Research and development (R&D) competence in the technology has also grown, with very strong areas of expertise established in niche areas at several South African higher educational institutes, as well as at the CSIR.

A number of promising market applications have been identified for AM in South Africa. South Africa has abundant mineral reserves and is the world's second largest[2] producer of Ilmenite and Rutile, from which Titanium (Ti) pigment is extracted. South Africa is also the second largest mining producer of Vanadium[3]. Aluminium and Vanadium are key to titanium alloys used in the medical and dental implants and the aerospace manufacturing industries. These markets also require highly complex designs for parts, or parts that have to be customised, which provide an excellent opportunity for value addition through AM in these markets. The direct tooling market in South Africa amounts to an estimated R13 billion[4], with an additional R2 billion for maintenance and servicing. The tooling industry is an important industry segment; it supports key manufacturing sectors such as the automotive, aerospace, consumer goods, packaging and electronics sectors. AM has the potential to contribute to the rejuvenation of South Africa's tooling and foundry industries by introducing innovative technologies to improve tool performance, as well as time to market.

Because of the diverse application base of AM, it is also impacting on small, medium and micro enterprises (SMME) nationally. AM is used as a prototyping and production tool in a wide range of applications in industry, contributing positively to gross domestic product (GDP). The jewellery industry, for example, makes extensive use of AM to ensure competitiveness in a global market place. The sale of so-called 'low-cost 3D printers' is in a rapid growth phase with hundreds of systems sold annually.

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[2] *U.S. Geological Survey, Mineral Commodity Summaries, January 2015, p 172*

[3] *U.S. Geological Survey, Mineral Commodity Summaries, January 2015, p 177*

[4] *Tooling Association of South Africa*

By analysing identified local opportunities and considering the local capabilities and competencies, four priority focus areas were identified, supported by a set of enabling complementary technologies. The four main priority focus areas identified in the South African Additive Manufacturing Strategy are:

- Qualified AM technology for final part manufacturing for the medical and aerospace markets;
- AM technology for impact in the traditional manufacturing sectors;
- New AM material and technology development; and
- SMME development and support programmes.

Programmes that will support these priority areas have been identified. Programmes in support of AM in the formal education sector as well as activities that will raise awareness of AM amongst industry, entrepreneurs and the public were also identified and addressed.

The strategy also makes recommendations regarding a structure to be established to manage the implementation of programmes in support of the priority areas identified. It is proposed that an AM Steering Committee consisting of representatives from key industry segments and associations, government and AM experts from R&D institutions, is established to primarily provide the strategic leadership with respect to the further refinement of the SA Additive Manufacturing Strategy and to oversee the implementation of programmes in support of the defined priority focus areas.

AM technology is in a strong growth phase, with public interest and R&D investment in the technology at very high levels. South Africa has a comparative advantage with respect to large mineral reserves, and has R&D capabilities in niche areas in AM that compare favourably with the best in the world. Programmes to further unlock the potential of AM in selected focus areas will ensure that South Africa becomes a leading global player in these fields of AM.

Anthropomorphic prosthetic hand (Source: George Vicatos and Severin Tenim (UCT))

Contents

List of acronyms

3D	Three-dimensional
AM	Additive Manufacturing
AMS	Aerospace Materials Specifications
AMTS	National Advanced Manufacturing Technology Strategy for South Africa
ASTM	American Society for Testing and Materials
BPM	Ballistic Particle Manufacturing
BSI	British Standards Institution
CAD	Computer Aided Design
CAT	Computerised Axial Tomography
CEN	European Committee for Standardisation
CMM	Coordinate Measuring Machine
CNC	Computer Numerical Control
CRPM	Centre for Rapid Prototyping and Manufacturing
CSIR	Council for Scientific and Industrial Research
CT	Coherence Tomography
CUT	Central University of Technology, Free State
DIY	Do-it-yourself
DMLS	Direct Metal Laser Sintering
DMRC	Direct Manufacturing Research Centre
DST	Department of Science and Technology
the dti	Department of Trade and Industry
EBM	Electron Beam Melting
EU	European Union
FEM	Finite Element Modelling
GE	General Electric
HCD	Human Capital Development

HEI	Higher Education Institution
HIP	Hot Isostatic Pressing
I2P	Idea to Product
ILT	(Fraunhofer) Institute of Laser Technology, Germany
IP	Intellectual Property
ISO	International Organisation for Standardization
ITC	(Aerosud) Innovation and Training Centre
LEAP	Leading Edge Aviation Propulsion
LENS	Laser Engineered Net Shaping
LS	Laser Sintering
MAM	Metal-based Additive Manufacturing
MIT	Massachusetts Institute of Technology
MRI	Magnetic Resonance Imaging
MSM	(CSIR) Material Science and Manufacturing
MTI	Morris Technologies Incorporated
NDT	Non-destructive Testing
NECSA	Nuclear Energy Corporation of South Africa
NLC	(CSIR) National Laser Centre
NRF	National Research Foundation
NTU	Nanyang Technological University
OEM	Original Equipment Manufacturer
P3DP	Personal 3D Printer
PMO	Portfolio Management Office
RAPDASA	Rapid Product Development Association of South Africa
R&D	Research and Development
RDI	Research, Development and Innovation

RMIT	Royal Melbourne Institute of Technology
RP	Rapid Prototyping
RSA	Republic of South Africa
SA	South Africa
SAA	South African Airways
SAE	Society of Automotive Engineers
SASAM	Support Action for Standardisation in AM
SET	Science, Engineering and Technology
SLA	Stereolithography
SLS	Selective Laser Sintering
SMME	Small, Medium and Micro Enterprise
STAIR	Standardisation, Innovation and Research
SUN	Stellenbosch University
TASA	Tooling Association of South Africa
TC	Technical Committee
TEI	Tertiary Education Institutions
TIA	Technology Innovation Agency
TiCoC	Titanium Centre of Competence
TRL	Technology Readiness Level
UK	United Kingdom
UNM	Union de Normalisation de la Mécanique
USA	United States of America
VDI	Association of German Engineers
VUT	Vaal University of Technology

Section A: Additive Manufacturing

The International Landscape

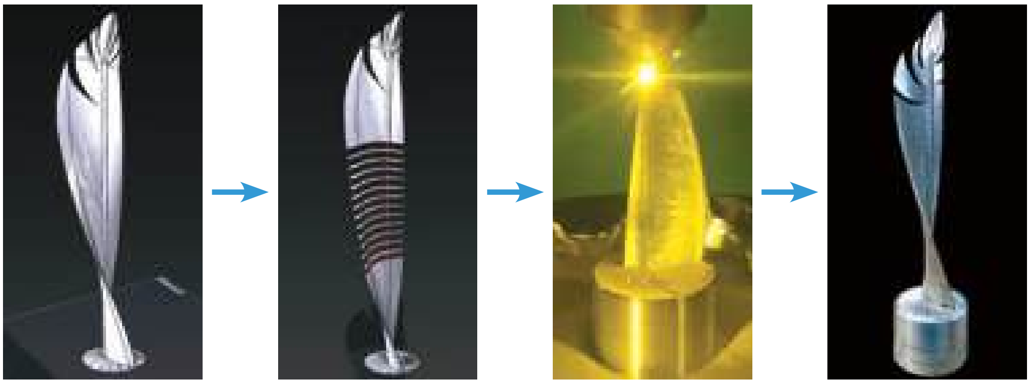
> Additive manufacturing is “the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies, such as traditional machining.”
>
> – ASTM definition

Production of dental crowns on a powder bed fusion system (Source: EOS)

A1 Global trends and drivers

A1.1 Introduction to Additive Manufacturing

Additive Manufacturing (AM) started in the mid-1980s as a rapid prototyping technology with the invention of stereolithography (SLA) by Charles Hull. This invention formed the basis of a new company, 3D Systems, which today is one of the major players in AM. Over the years the technology developed from a prototyping technology into a versatile new manufacturing technology which is increasingly being adopted for producing fully functional final parts. Although initially referred to as rapid prototyping, AM has been defined by the American Society for Testing and Materials (ASTM) as the standard terminology that describes the process of layered manufacturing[5]. Some of the other terminologies that are often used by the public, or have a more historic context, include rapid prototyping, rapid manufacturing, direct manufacturing and 3D printing.



AM process flow demonstrated – From CAD design, software slicing of the design to printing of the component (Source: CSIR and NSTF)

The variety of materials that can be used to produce objects has expanded significantly since the advent of SLA. Today it is possible to 3D print objects from most materials, including paper, metals, plastics, ceramics, glass and organic materials including living cells. The use of AM is just as widespread with many applications in the automotive, tooling, aerospace, medical implants and devices, jewellery and crafts and architectural industries. The largest uptake in terms of AM machine platforms is in the consumer market where do-it-yourself (DIY) enthusiasts and hobbyists[6] use the technology to create real objects from their own designs.

AM brings a number of advantages to the manufacturer compared to the more traditional manufacturing technologies such as milling, casting and forming technologies. It is often

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[5] *ASTM F2792-12 Standard Terminology for Additive Manufacturing Technologies*

[6] *Collectively called the “maker” movement*

explained that AM provides designers with more design freedom to realise their product offering compared to traditional manufacturing. The phrase “complexity comes for free” is regularly used when referring to AM. This is largely due to the fact that a component is formed layer by layer, with the possibility to create intricate shapes and internal features that are typically not possible with traditional manufacturing technologies.

Another significant advantage compared to traditional manufacturing is the ability of AM to reduce material wastage during the manufacturing process. This becomes a very important factor if one works with exotic or high-value materials, materials that are difficult to machine, or where traditional manufacturing methods yield a high percentage of material waste. AM also allows the manufacture of an improved or more complex design of an assembly to reduce the number of parts in the assembly, thereby reducing the requirement of assembly after the manufacturing process. Since each component is ‘printed’ individually, directly controlled by a print file generated in a computer aided design (CAD) environment and without the need for tooling, AM offers more opportunity for customisation and manufacture-for-purpose compared to traditional manufacturing. An increased focus on industrialising this manufacturing technology and developments to produce AM machines with larger build envelopes make batch production and mass customisation possible, with potentially significant cost savings for the manufacturer compared to conventional manufacturing. Design changes can also easily be incorporated into the next prototype or final part produced with AM, and therefore accelerates the time to market.

A further advantage is the possibility of distributed manufacturing where on-site production of parts becomes possible, compared to the current model where large factories produce parts being distributed through complex distribution channels. AM has the possibility of replacing some physical distribution channels with digital distribution channels where designs are created centrally, but manufacturing happens on-site in a distributed network.

AM is generally considered as the one of the key technologies for manufacturing in the future. AM was listed as one of the 10 breakthrough technologies in 2013 by the Massachusetts Institute of Technology (MIT) review[7] and was also listed as one of the top twelve disruptive technologies in the McKinsey Global Institute Analysis 2013 report[8]. The McKinsey report predicts that by 2025 up to 50% of products in relevant categories will be replaced by 3D printing techniques, or “direct product manufacturing”. These products can potentially also cost 40% to 55% less due to the lower material usage, reduced tooling costs and savings with respect to handling costs. The United States of America (USA)-based Institute for Defence Analysis listed AM as one of four technology areas that will impact the advanced manufacturing landscape in the next twenty years[9].

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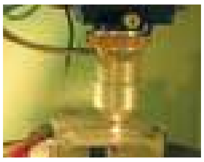
[7] *www.technologyreview.com*

[8] *Disruptive technologies: Advances that will transform life, business, and the global economy, May 2013*

[9] *IDA Paper P-4603, March 2012*

The ASTM has defined standard terminology for the seven technologies that make up AM[10]. These are:

Technology		Materials	Typical markets
	**Vat polymerisation** An AM process in which liquid photopolymer in a vat is selectively cured by light activated polymerisation.	▸ Photopolymers	▸ Prototypes ▸ Jewellery industry
	**Material jetting** An AM process in which droplets of build material are selectively deposited.	▸ Polymers ▸ Waxes	▸ Prototypes ▸ Moulds for castings ▸ Jewellery industry
 	**Binder jetting** An AM process in which a liquid bonding agent is selectively deposited to join powder materials.	▸ Gypsum ▸ Foundry sand ▸ Polymers ▸ Metals	▸ Prototypes ▸ Patterns for castings ▸ Creative industries ▸ Final parts (metals)
	**Sheet lamination** An AM process in which sheets of material are bonded to form an object.	▸ Metals ▸ Paper	▸ Prototypes ▸ Tooling ▸ Final parts (metals)

Technology	Materials	Typical markets
  **Material extrusion** An AM process in which material is selectively dispensed through a nozzle or orifice.	- Polymers	- Prototypes - Consumer goods - Tooling - Final parts
  **Powder bed fusion** An AM process in which thermal energy selectively fuses regions of a powder bed.	- Polymers - Metals	- Prototypes - Tooling - Final parts
  **Direct energy deposition** An AM process in which focused thermal energy is used to fuse materials by melting as they are being deposited.	- Metals	- Final parts - Refurbishment and repair

Images courtesy of 3D Systems, Ahrlac, Arcam, CSIR, CUT, ExOne, Mcor Technologies, Rapid3D, Stratasys

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[10] *ASTM F2792-12a*

A1.2 Key industries investing in Additive Manufacturing technology

Several key industries in the USA, Europe, and Asia are investing in AM technology, and most of them are central to the global manufacturing economy. The global economy is valued at about $80 trillion. Manufacturing accounts for more than 16% of the total, equating to more than $12.8 trillion[11]. If AM were to grow to capture just 5% of this global manufacturing market, the AM market would develop to $640 billion annually, which is about 155 times larger than it is today. This potential has driven a great deal of interest from investors in AM.

The use of AM by industry has a direct effect on investment. Wohlers Associates conducts an annual survey to determine the key industries that are adopting AM. The most recent survey results, published in Wohlers Report 2015[12], indicate that industrial and business machines is now the leading industrial application area, compared to consumer products and electronics which was the leading industrial sector in the preceding eight years (Figure 2). The automotive sector ranks third and medical and dental has also established itself as a strong sector year after year.

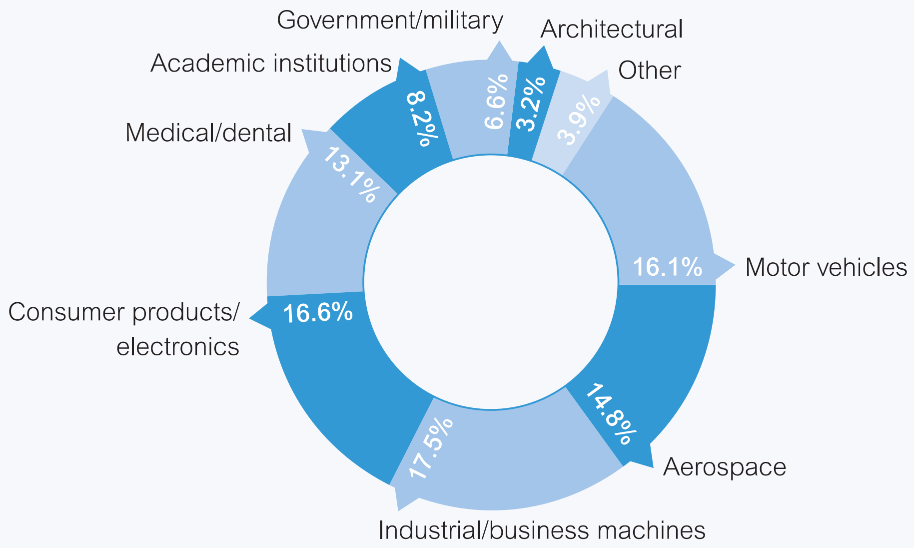

FIGURE 2: Industry adoption of AM technologies (Source: Wohlers Report 2015)

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[11] *Wohlers Report 2015 – 3D printing and Additive Manufacturing State of the Industry*

[12] *Wohlers Report 2015 – 3D printing and Additive Manufacturing State of the Industry*

A 2013 report by the Direct Manufacturing Research Centre, located at the University of Paderborn in Germany, also identifies the aerospace, automotive and electronics industries as being the most promising business opportunities for the application of AM in the future[13]. Several industrial sectors have made significant investments over the past few years, as described below.

A1.3 Additive Manufacturing service sector

Shapeways, a spinoff from the lifestyle incubator of Royal Philips Electronics, is an AM service provider with facilities in a number of countries including the Netherlands. Its headquarters is in New York City where it also has an impressive manufacturing facility with many industrial-grade machines. Customers upload their files to Shapeways, receive an instant quote in a variety of AM materials and technologies and can then order parts. Designers can also set up a shop and sell their AM products to customers through the Shapeways virtual storefront. Since being founded in 2007, Shapeways has received five rounds of investment valued at over $50 million.

Thingiverse[14] is a website used by practitioners of 3D printing dedicated to the sharing of self-created digital design files. It also carries open source hardware designs licensed under the GNU General Public License or Creative Commons licences, users choose the type of user licence they wish to attach to the designs they share. 3D printers, laser cutters, milling machines and many other technologies can be used to physically create the files shared by the users on Thingiverse. It is widely used in the DIY technology and Maker communities[15].

A1.4 Additive Manufacturing system manufacturers

Several significant investments by AM system manufacturers occurred in 2012 and 2013. As an example, Stratasys and Objet, two major AM manufacturers, merged in 2012. In 2013, Stratasys acquired MakerBot Industries, a leader in the field of desktop 3D printing, for more than $400 million.

3D Systems has been actively investing over the past three years, with 40 acquisitions (as of mid-March 2014) including Z Corp., Freedom of Creation, Quickparts, Phenix Systems, Geomagic, INUS (makers of Rapidform), Village Plastics, The Sugar Lab, Bespoke Innovations, a Xerox product design and engineering group, and Gentle Giant Studios.

Examining the performance of the stock of the largest two AM companies, 3D Systems and Stratasys, from March 2012 to March 2014, gives a good indication of the level of investor interest in AM. The market capitalisations for these companies show impressive growth over the previous years – in mid-March 2014, the two companies were valued at more than $12 billion.

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[13] *Thinking ahead the Future of Additive Manufacturing – Innovation Roadmapping of Required Advancements, DMRC, University of Paderborn*

[14] *https://www.thingiverse.com*

[15] *https://en.wikipedia.org/wiki/Thingiverse*

FIGURE 3: Performance of Stratasys shares from March 2012–February 2014 (Source: Edgar Online)

A1.5 Examples of successful government interventions

Several USA government departments and agencies pooled money to create America Makes, also known as the National Additive Manufacturing Innovation Institute. It is a public-private partnership developed to increase USA manufacturing competitiveness by advancing AM technology. Initial public funding was $30 million and in March 2014, total public funding rose to $50 million. An additional $50 million will come from other sources, including private industry and educational and research institutions, in a 50:50 cost share.

In Europe, MANUFUTURE is an industry-led initiative which was established in 2004 to define and implement research and innovation strategies to drive and increase manufacturing output. The Strategic Research Agenda is produced by the AM Sub Platform initiated by MANUFUTURE. The purpose of the Strategic Research Agenda is to regularly review the important areas that need research and development (R&D) efforts at a European level to advance the use and adoption of AM. As part of the strategic process several roadmaps were developed, and in "Factories of the Future 2020" produced in November 2012, AM was listed as a "key advanced manufacturing" process. Some recent highlights of government-supported activities in Europe include the following:

- In November 2012 the UK Government announced a £7 million investment in AM technologies for R&D, Higher Educational Institutes and science;
- In Germany the Direct Manufacturing Research Centre at the University of Paderborn has a budget of €11 million for a five-year programme to advance AM. This funding was secured from the local government of North-Rhine-Westphalia as well as co-investment from industry; and
- The European Framework Programme has invested more than €60 million in AM since 2008 and continues to invest in large projects to advance AM[16].

The RMIT Advanced Manufacturing Precinct in Melbourne, Australia, is funded by more than $20 million in investment from the Australian government. The precinct opened in 2011 with an initial Victoria state investment of $7 million, followed by an additional $13 million in 2012 from the government, industry and Higher Educational Institutes. AM accounts for half of Victoria state's manufacturing output and the intent is for the Advanced Manufacturing Precinct to help Victorian companies develop new, sustainable products with state-of-the-art equipment. The precinct includes a number of selective laser melting, direct metal laser sintering, fused deposition modelling, and photopolymer-based PolyJet systems.

The Nanyang Technological University Additive Manufacturing Centre in Singapore received investment of over $30 million from Singapore's Economic Development Board in 2013. Its goal is to bring together disparate AM-related research efforts from across several organisations and universities in Singapore and become a national centre of excellence in AM. The centre has a range of AM facilities with metal-, polymer- and plaster- or ceramic-based technologies.

The Peoples' Republic of China has experienced significant investment in AM, with more than $245 million invested in a six-year project that will boost development of AM. This investment is coming from provincial and city governments and is likely to help China become a leading player globally in AM.

A1.6 Worldwide growth of Additive Manufacturing

New AM processes, machines, materials and applications are being developed at an unprecedented rate, and there is strong demand for providers of AM products and services. The compound annual growth rate of worldwide revenues produced by all products and services over the past 25 years is an impressive 27%. The annual growth rate during the period 2011–2013 was 32.3%[17].

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[16] *http://cordis.europa.eu*

[17] *Wohlers Report 2015 – 3D printing and Additive Manufacturing State of the Industry*

The following chart (Figure 4) shows revenue growth for AM products and services worldwide since 1993. As can be seen, a significant increase has occurred since 2010.

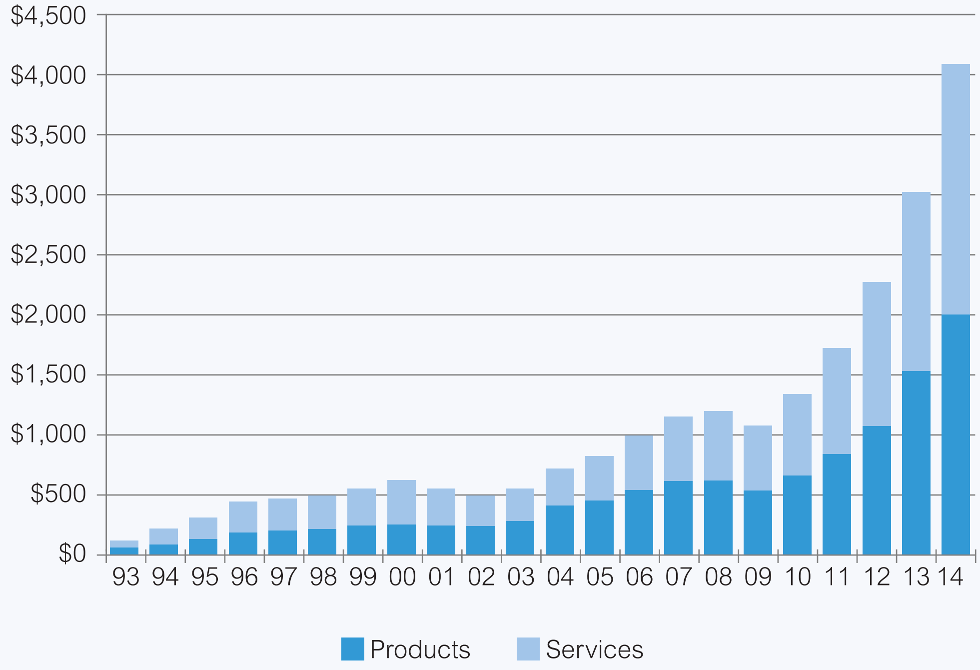

FIGURE 4: Total revenue ($ million) of AM products and service worldwide (Source: Wohlers Report 2015)

The unit sales growth of industrial AM systems continues at a strong pace. The average annual growth rate from 1989 to 2014 was 26.3%. Investments by machine developers and manufacturers can be correlated with this growth.

The number of AM-related patents issued is a good lagging proxy indicator of the level of investment in R&D. The rapid increase of issued patents over the past few years demonstrates an increase in interest, and probably investment. More than 80% of these patents were issued to companies, rather than individuals, Higher Educational Institutes or research organisations.

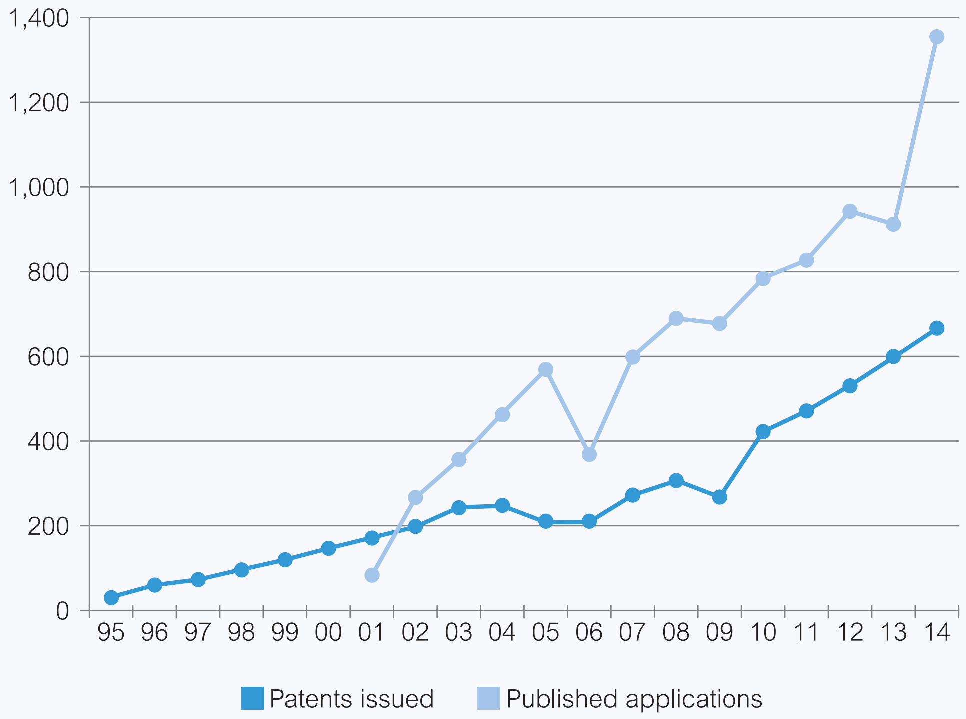

FIGURE 5: AM-related patent activity
(Source: Castle Island and Wohlers Report 2015)

A1.7 Investment in new technologies

Many new AM processes and related technologies have been developed over the past few years, or are still under development. These include the following:

- **Co-creation or co-design software:** This area of research aims to develop specialised design software that allows the customer to participate in the design process to create more personalised products. Much of this effort has been focused on web-based tools.
- **Design tools for AM:** There is on-going effort to produce software that enables designers to take full advantage of the unique capabilities of AM processes in the design of parts. Examples are the inclusion of lattice or mesh structures to reduce material and weight and the consolidation of many parts into one.
- **Topology optimisation software:** This is a special area of design for AM that aims to use as little material as possible to optimise the strength to weight ratio of a part. Topology optimisation is particularly important to the aerospace industry and niche industries such as Formula 1 and MotoGP™.
- **Medical imaging and processing software:** Effort is underway around the world for improved software that automates the extraction of 3D data from Coherence Tomography (CT) and Magnetic Resonance Imaging (MRI) scans, ultrasound, and other medical imaging technologies.

- **Post-processing:** Depending on the material and process used, parts manufactured by AM may require considerable post-processing. This can include the removal of support material, improvements to the surface finish, heat treatment to relieve residual stress and the addition of colours and coatings. Work is underway to improve and streamline much of the required post-processing, although it is often application-dependent.
- **Hybrid AM:** This refers to the combination of additive and subtractive technologies used to produce parts. Material is first deposited with an AM process and then Computer Numerical Control (CNC) machining is used to remove material, all in one machine. Alternatively, complex features can be added via AM to basic machined shapes to produce complex components. Applications of hybrid AM can be found in, among others, the tooling industry.
- **Inspection and non-destructive testing:** The AM industry needs better methods for testing parts to ensure they meet specific quality standards.
- **New materials:** Interest in more AM materials, including polymers, metals, functionally graded materials, ceramics, composites and biomaterials, continues to grow.
- **New processes:** The competition is to develop new AM processes that produce better parts faster, and at a lower unit cost. Most new AM systems are incremental improvements of established technologies, and breakthrough innovations are rare.

A1.8 Future areas of growth

Since the 1980s, AM technologies were developed and used principally for prototyping applications, testing ideas before taking them to market. During the past few years, however, AM technologies have been used increasingly to manufacture real production parts, as shown in Figure 6. By 2014, final parts manufacture had grown from 3.9% to 42.6% of the total product and service revenues from AM.

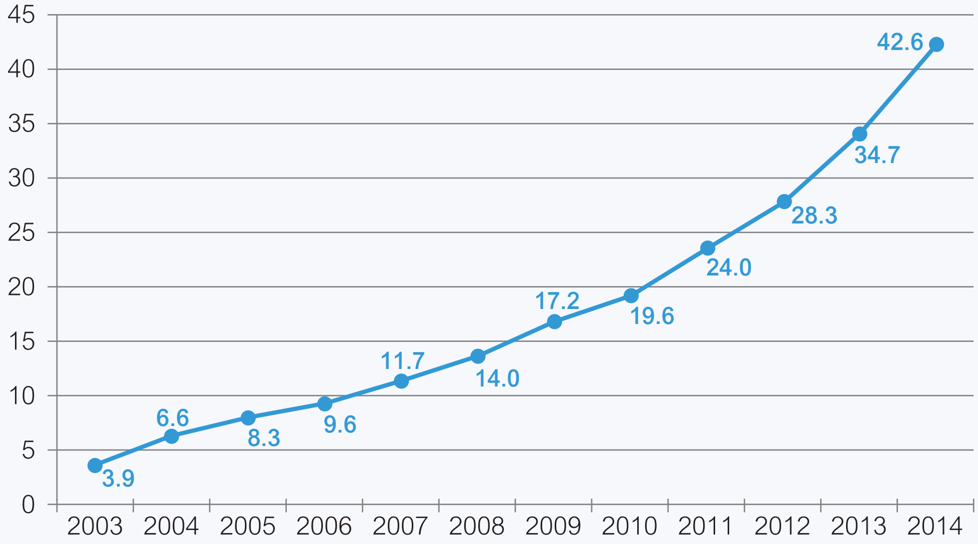

FIGURE 6: Percentage share of real part production in total AM market (Source: Wohlers Report 2015)

The application areas of AM in 2013 are presented in Figure 7.

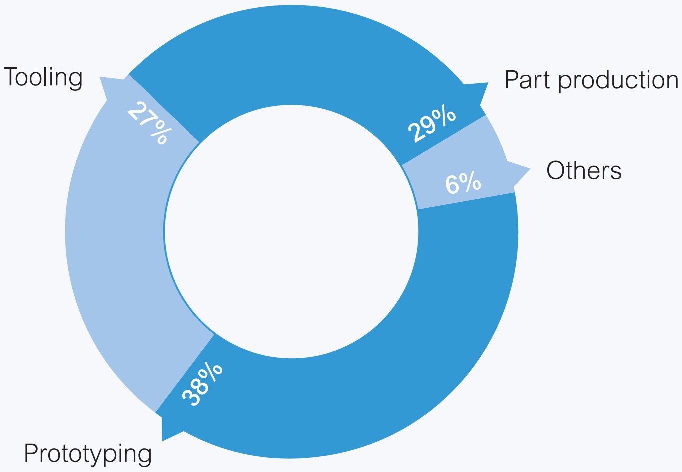

FIGURE 7: Application areas of AM (Source: Deloitte University Press)

Interest in materials has also grown beyond basic metals and polymers to a new range of materials, including precious metals and super-alloys, biomaterials, food ingredients, conductive polymers, construction materials and high-performance ceramics.

With these new developments, we have realised the opportunities possible with AM. The opportunity for rapid growth in AM over the coming decade is vast, and it is useful to consider visualising current applications as simply the tip of the iceberg (Figure 8).

The part of the iceberg above the surface depicts the types of parts and applications that AM has enjoyed for many years. Just beneath the surface are examples still in development or which have been established at only a few organisations. As one descends further, the applications presented are not as certain but they provide a glimpse of how the technology may develop in future.

It took the AM industry 20 years to reach a size of $1 billion in size. It took just five more years for the industry to generate its second $1 billion. Wohlers Associates forecasts that the worldwide sale of AM products and services will reach $7 billion worldwide by 2016 and $21 billion by 2020. Predictions, however, become more uncertain if the unknown potential of emerging technologies, such as bio-printing, food, fashion products and integrated electronics, are considered.

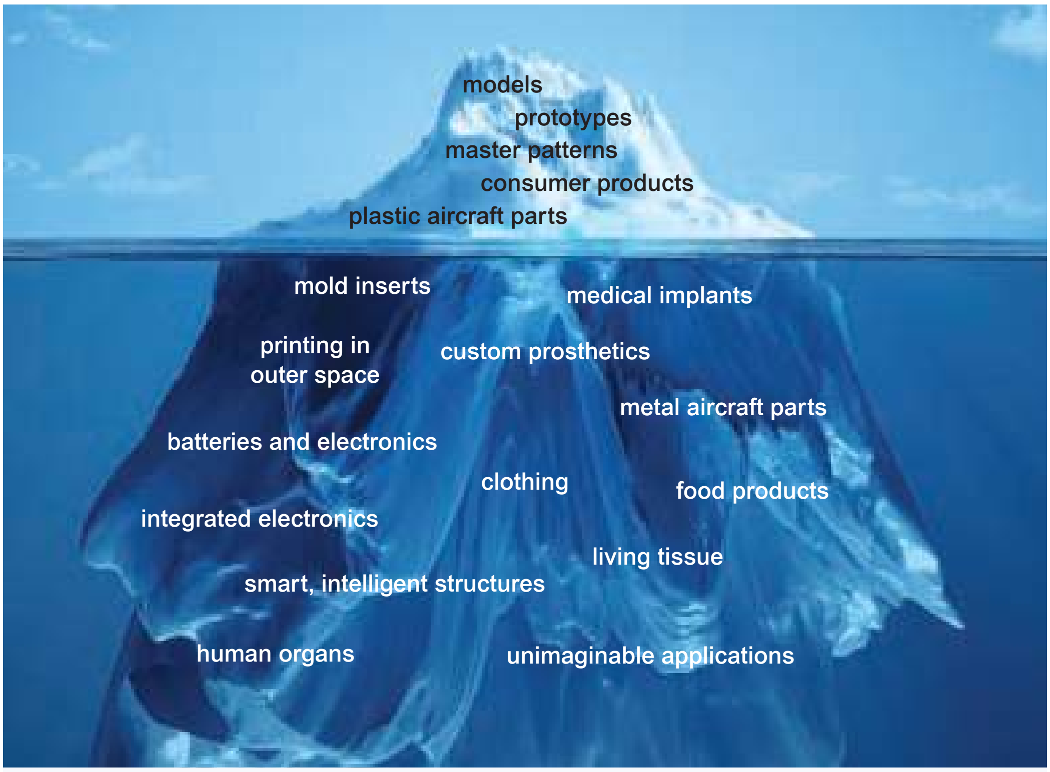

FIGURE 8: Present and future possible applications of AM
(Source: Wohlers Report 2014)

A1.9 Some user success stories

Many companies in the US, Europe and Asia have experienced success in developing and applying AM to the production of parts that go into final products. Most of this work represents pioneering effort coupled with a great deal of investment, determination and risk.

Align Technologies, with its Invisalign dental alignment system, represents a true success story for AM. For many years the company has used AM to manufacture patterns to produce custom dental aligners. Annually, the company manufactures millions of aligners from SLA patterns. The process starts with developing an impression of a patient's teeth. The teeth are scanned and digitally manipulated for corrective action by a dental technician. A set of patterns is then printed using SLA, and these are used as patterns for a thermoforming operation in which thin plastic material is formed over the SLA parts. A laser engraver is used to mark individual patient and traceability information onto the aligners. A multi-axis CNC machine trims the excess material, and the aligners are polished in a vibratory tumbler to remove any sharp edges. Finally, they go through an automated packaging plant to be packaged and shipped to the patient.


Acetabular cup produced with EBM technology (Source: Arcam)

Ala Ortho and Lima Corporate, two orthopaedic implant manufacturers based in Italy, have produced tens of thousands of titanium acetabular cups by electron beam melting (EBM). One of the features that makes the EBM process superior to conventionally manufactured hip joints is the capability of producing an outer trabecular surface that encourages osteo-integration, with bone growing into the hip cup, thus giving a stronger and more permanent joint. The hip cups are another example of AM being used in conjunction with traditional manufacturing (hybrid manufacturing), as the inner surfaces of the acetabular cups are CNC machined where smooth surfaces are needed.

Companies such as Phonak, Siemens, Widex and Starkey use AM to produce about 90% of the world's custom plastic shells for in-the-ear hearing aids. Each patient's ear is unique, making AM ideally suited to producing a unique hearing aid that perfectly fits each patient. The patient's ear canal is first filled with a material such as silicone to form a precise impression of the canal. The impression is then 3D scanned and the data are imported into specialised hearing-aid design software. The hearing aid shells are then manufactured, using SLA or another AM process, and assembled.

For years, Boeing has used plastic laser sintering (LS) to manufacture environmental control system (ECS) ducting for both military and commercial aircraft. Currently, the company is manufacturing ECS ducting, and other parts for 16 different aircraft. To date, tens of thousands of these laser-sintered parts are in service on hundreds of planes—without a single failure.

In November 2012, GE Aviation acquired Morris Technologies Inc (MTI), a leading service provider of metal parts made by powder bed fusion. In early 2013, GE announced that it would make fuel nozzles by AM for its next-generation LEAP engine. The company was expected to begin to manufacture more than 30 000 nozzles annually, in early 2015. The company plans to invest $3.5 billion in advanced manufacturing, including AM technologies, between 2013 and 2018. The fuel nozzle for GE's LEAP engine is an excellent example of the 'complexity for free' advantage that AM provides. The new nozzle design is 25% lighter and up to five times more durable than the previous nozzle made from 20 different parts[18].

GE LEAP engine nozzle produced in Inconel (Source: GE)

Jewellery is a large global industry estimated at over $220 billion. AM has allowed individual, small-scale designers and artists to produce products for sale to the general public. Online 3D printing content and sales portals such as Shapeways carry more than 25 000 jewellery and fashion-related products, all designed to be 3D printed.

Jewellery patterns
(Source: Rodney Chandler)

A New Zealand-based company, Oceania Defence, is producing a range of titanium rifle suppressors that are now being sold to the New Zealand (NZ) and Canadian defence forces. The suppressor design combines porous titanium and complex inner baffles to dissipate the gases and sound. The suppressors have been reported to reduce the dB level of the weapon to below that required for hearing protection. The NZ Titanium Development Association produced the suppressors.

ODD Guitars produces a range of 3D-printed electric guitars. The intricate bodies of the guitars are manufactured by LS. A key point in this example is that AM allowed the business to get started with little capital risk compared to conventional manufacturing that would have required a sizeable capital investment. ODD Guitars is thus another good example of AM's 'complexity for free' advantage.

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[18] *http://www.3dprinterworld.com/article/ge-aviation-receives-award-for-leap-engine-fuel-nozzle*

Guitars designed by Olaf Diegel (Source: Olaf Diegel)

A1.10 Some recent failed ventures

There are numerous examples of failed ventures and investments in AM. They include attempts at producing injection mould and die cast tooling with AM as well as new processes and new business models that were ill conceived or poorly executed. Most of these failures are not publicised, so it is easier to discuss general areas that have not been successful.

A1.10.1 Tooling

In the early to mid-1990s, with the advent of selective laser sintering (SLS) systems that were capable of producing metal parts, high expectations developed within the injection moulding community. The hope was to 3D print complex injection mould inserts. Unfortunately, the realities of what was possible with AM at the time did not match up with the hype. Early SLS systems used polymer-coated metal particles. The laser melted the polymer particles together to produce a green part that needed to be infiltrated with bronze in a furnace. The accuracy and repeatability of these systems were low, which was not desirable for tooling applications. Also, the surface finish was poor. By the end of the 1990s, after a lot of investment in rapid tooling research across many AM processes, the industry was disenchanted with the potential of AM to produce moulds and dies. Interest in rapid tooling has, however, revived in recent years with the development of real metal production systems such as EBM and direct metal laser sintering (DMLS).

A1.10.2 Slow uptake of processes

Several AM technologies were developed in the past 25 years that were commercially unsuccessful. Technologies such as rapid spray process and ballistic particle manufacturing (BPM), for example, offered interesting potential but never developed into commercially viable systems. Companies that sold AM systems at one time that are no longer in operation include Cubital, Helisys, Kira Corp., Solido and BPM Technology. Others that did not achieve commercialisation include BMT, Desktop Factory, Laser 3D, Light Sculpting and Röders. Even some of the more mainstream directed energy deposition techniques, such as Optomec's LENS and BeAM's EasyCLAD, have produced commercial systems but have experienced 'soft' sales in comparison to other technologies.

A1.10.3 Shared Replicators fractional ownership model

In 1999, Shared Replicators pioneered a fractional ownership programme for top-of-the-line industrial AM equipment. The idea was to create a cooperative arrangement so that people who bought shares in the business would be able to access a particular technology when it was needed. The concept was to offer product developers access to equipment that they could not afford individually. However, the concept never gained enough traction and ultimately failed.

A1.10.4 Media hype and confusion

The current media hype around AM and 3D printing will inevitably lead to some disenchantment with the technologies, especially since many people do not understand the distinction between low-cost 3D printers, generally costing less than $5,000, and industrial systems that typically sell from $20,000 to more than $1 million. Both are important classes of technology deserving of media attention, but a problem arises when the media show parts that were made on a million dollar machine next to a picture of a low-cost printer without pointing out that it is impossible to make the part shown using a desktop printer. Anecdotal evidence suggests that many people have purchased inexpensive 3D printers and have been disappointed by the quality of the parts they produce.

AM is a revolutionary technology that will have impact in a number of industries, but it is important to understand the strengths and limitations of this technology. A number of myths exist around this technology and some of these will be addressed here.

Myth	Reality
AM is fast	One of the many myths regarding AM is that it is a rapid technology. In fact, when compared to technologies such as injection moulding, AM is actually a very slow process. Depending on the size of the part, parts can take hours or even days to manufacture. **However** AM does have advantages in terms of speed when considering the complete lifecycle of a product, especially with low volume manufacturing. AM requires no tooling and little to no programming. Design changes can be applied in CAD and new products can be produced immediately without waiting for new tooling designs and tooling production. Also, with other technologies, the more complex the part the longer the manufacturing cycle. This is not the case with AM since part complexity has little or no impact on the speed of the process.

Myth	Reality
AM is a 'green' technology	There is a perception that AM processes consume less energy when compared to other manufacturing techniques. Research has shown that this is typically not the case and that AM technologies are in certain areas even more energy intensive than its traditional counterparts. **However** When looking at the full value chain, AM can certainly reduce the use of resources. AM reduces material waste by great margins when compared to processes such as CNC machining. By reducing material waste, you are not only consuming less material, but are also reducing shipping cost of raw material and scrap. The fact that no tooling is required contributes to an additional reduction in the carbon footprint of AM parts. However, one of the main advantages of AM is the design freedom that the technology offers. By changing the design of parts, AM can be used to reduce the weight of parts, thereby reducing the amount of material used for parts and, in the case of the automotive and aviation industries, reduce the fuel consumption and further reduce the carbon footprint of these industries. Somasekharappa[19] provided an example where the redesign of an exhaust nozzle for AM resulted in a decrease of the component's weight by 45% without compromising its original design strength.
You can print anything you can think of	This is a perception that is certainly true to a large extent and which is actually one of the main advantages of AM. AM offers the designer a lot of freedom that allows weight reduction, integration of multiple parts into a single part, increased complexity, functionality and in some cases also durability of the part. **However** AM is NOT a technology without design rules, it has a different set of design rules which is important to understand. AM is a collective term for a wide range of technologies that can produce parts in different materials using different techniques and it is important to note that different rules apply to different technologies. Important factors to consider include wall thickness, support structures, tolerances, post-processing requirements, etc.

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[19] *Somasekharappa, M, Additive Manufacturing and Industrial Tooling (Part 2), 3D Printing Industry, 3dprintingindustry.com, July 4, 2013*

Myth	Reality
AM will replace conventional manufacturing	AM certainly has the potential to impact manufacturing in various sectors, especially in areas with relatively low volume production or mass customisation. Industries such as medical and aerospace, which are typically high-value, low volume industries will benefit from this technology in future. Other industries such as the dental industry and in-ear hearing aids have already been transformed by AM technology. Areas where the design freedom of the technology enables new and improved applications will also make extensive use of AM. **However** On a broad scale, AM will definitely not replace conventional manufacturing techniques, but will rather supplement or complement these. Modern-day manufacturing is largely based upon mass manufacturing of relatively simple components. AM is simply not equipped to handle the volume and speed requirements of traditional manufacturing such as injection moulding, nor can it compare with the cost of these processes when it comes to high volume, low value products.
3D printers are inexpensive	The expiration of certain patents in the field of AM has, in the last few years, triggered the development of hundreds of low-cost 3D printers. These units are typically below R50 000 per unit and can cost as little as R10 000. In South Africa, the installed base of these units is already past 3 000 and is growing daily. **However** It is important to note that currently these printers are mostly focused on a hobbyist market and, except for singular instances, these printers are not designed as production systems. Recent advances in print speed and material quality does allow them to be used in limited run manufacturing, or in some production processes around mould making, casting and vacuum forming. AM systems can be found with a wide range of capabilities (and prices) with the cost of some of these systems in excess of R10 million. It is critical to ensure that the right technology is used for the correct application.
You just press ‘print’ and voila!	Contrary to popular belief, it is not as simple to ‘print’ a 3D part as it is to print a photo on an inkjet printer. In most instances, a certain amount of software skill, as well as some additional equipment may be required to produce AM parts. Printing of any part is usually accompanied by preparation of CAD files, build parameter selection, machine setup, etc. Most parts also require some form of post-processing which can include processes such as support structure removal, surface enhancements, heat treatments, etc. **However** With regard to traditional manufacturing processes, AM has introduced a paradigm shift. Where manufacturing was typically only possible in industrial settings, AM is allowing the manufacture of highly complex parts almost anywhere. This feature of AM has triggered a range of different industries across the world and will continue to do so in future.

In the special report 'Hype Cycle for 3D Printing'[20], Gartner reports that the widespread adoption of AM as a manufacturing technology for real part production is between five and ten years away. Gartner Hype Cycles provide a graphic representation of the maturity and adoption of technologies and applications, and how these are likely to evolve over time. These cycles highlight the common pattern of over-enthusiasm, disillusionment and eventual realism that accompany each new technology.

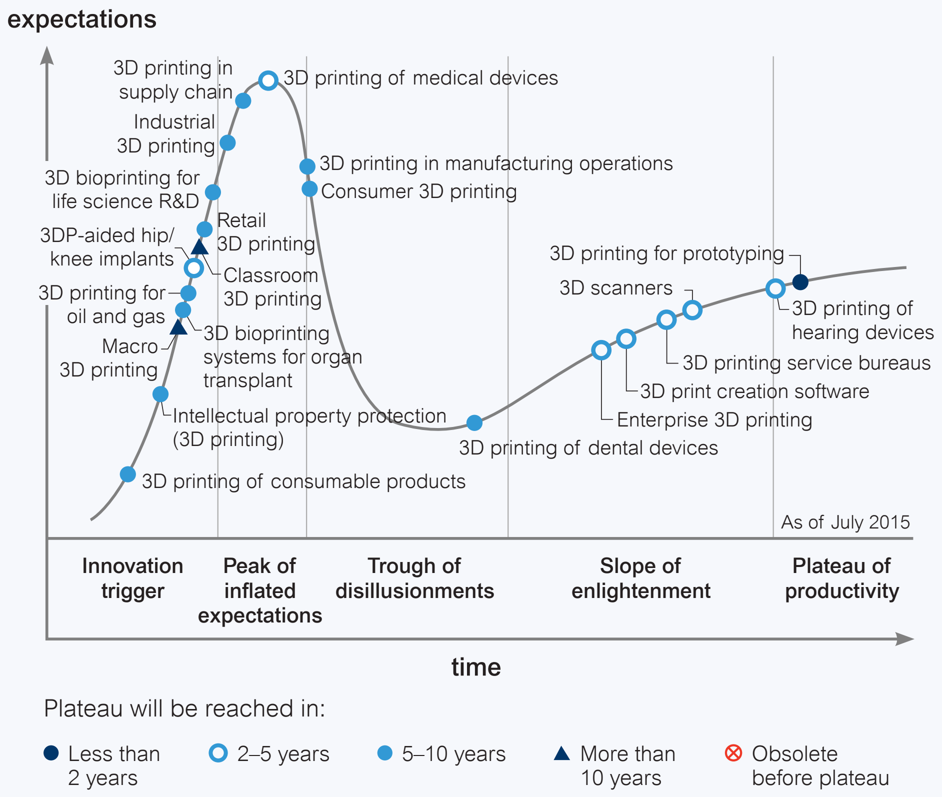

FIGURE 9: Hype cycle for 3D printing as of July 2015 (Source: Gartner)

The Hype curve reflects that some AM technologies are maturing faster than others and some are already in general use such as AM for prototyping, which has been the mainstay of the AM industry since its inception. In two to five years, there will be greater adoption of enterprise AM (nurtured in part by the continued acceptance and use of AM creation software), 3D scanners and 3D printing service bureaus. Medical device AM is also thought to be a leading application for AM, although AM-produced medical devices are predicted to face a trough of disillusionment before widespread adoption.

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[20] *Hype Cycle for 3D Printing, 2014, Gartner inc., July 2014*

Other technologies such as AM of large structures and classroom 3D printing are considered to be more than ten years away from mainstream adoption. The work on large structure AM shows great promise but has only just begun, while classroom 3D printing will be expensive and difficult to implement, especially in the face of other educational technologies competing for attention in the classroom.

A1.11 Examples of successful human capital development programmes

Successful programmes in AM are being conducted in the US, Europe and Asia for human capital development in AM. They are occurring at many levels, including secondary education, technical and community colleges, and four-year colleges and universities. Also, workforce training and continuing education programmes in AM are underway.

A1.11.1 Academic institutions

AM-related academic programmes around the world have grown rapidly in recent years. *Wohlers Report 2015* lists more than 100 academic institutions with programmes related to AM. Also, the vast majority of engineering and design programmes now include some exposure to AM, even if it is not stated as part of the curriculum. Relatively few institutions that offer technical subjects, such as engineering, do not have at the very least, a few desktop 3D printers for student use. Many listed in the *Wohlers Report* have more substantial AM centres with more advanced equipment. Also, low-cost 3D printers are now appearing increasingly in high schools and middle or junior high schools around the world.

A1.11.2 Maker spaces

The advent of desktop 3D printers has also had a sizeable impact on the 'maker' movement around the world. The maker community is made up of like-minded people with an interest in DIY design, innovation and manufacturing. 3D printing has proven to be a perfect vehicle for this passion. The series of Maker Faire events is a good indicator of the movement's growth. The 2006 launch of the first gathering in San Mateo, California, attracted 20 000 creators of varying skill levels. The 2011 event hosted more than 100 000 people, and the event has since spun off in other major cities in the US. On the more organised side of the maker movement, open-access 3D printing labs have been launched around the world. By 2013, MIT's FabLabs had more than 125 locations in 34 countries. South Africa's Idea 2 Product Labs have expanded into New Zealand, Sweden and the US.

A1.11.3 Government-funded knowledge centres

Many governments around the world have realised the potential of AM and have invested in knowledge centres to promote research in AM and to educate industry about the potential it offers. Some of these include the National Additive Manufacturing and Innovation Institute (America Makes), the National Centre for Rapid Technologies (RapidTech) in the US, the Direct Manufacturing Research Centre (DMRC) in Germany, RMIT University's Advanced Manufacturing Precinct in Australia, the New Zealand Product Accelerator, and the NTU Additive Manufacturing Centre in Singapore. In 2013, the central government of China formed the China 3D Printing Technology Industry Alliance. One goal of the alliance is to launch ten innovation centres in ten cities at a total cost of about $33 million.

Most universities have also had their AM research centres partially funded by their governments. Investments include provisions to educate industry and the general public about the potential of AM. South Africa has excellent examples of such centres including the VUT South Gauteng Science and Technology Park and the Centre for Rapid Prototyping and Manufacturing (CRPM) at the CUT.

A1.12 International standards development

On an international level, the need for standardisation in the field of AM has been identified and a number of standards organisations have started to respond. ASTM and ISO are the two main contributors in this field and a number of standards have already been developed and published specifically for AM.

ASTM F42 and ISO TC 261, which are the respective AM committees within these organisations, signed a unique collaboration agreement regarding the development of AM-related standards that entails that ASTM and ISO standards can be co-branded. This agreement ensures that standards are being developed at a faster rate, as these organisations are collaborating in the standards development process. The Rapid Product Development Association of South Africa (RAPDASA) is a member of ASTM F42 and also has a seat on the Executive Committee.

Many organisations are involved in the development of standards for AM. A list with some of the main players involved is presented in the table below.

Involvement of international standards bodies in AM standards development

ASTM F42	ASTM International is a globally recognised leader in the development and delivery of international voluntary consensus standards. Committee F42 is developing standards specifically for AM and has already published a number of standards.
ISO TC261	ISO is the International Organisation for Standardisation. TC261 is the technical committee on AM within ISO and is represented by standardisation organisations from 18 different countries internationally.
SASAM	SASAM (The Support Action for Standardisation in AM) is tasked with integration and co-ordination of standardisation activities across Europe in the field of AM. SASAM recently published a Standardisation Roadmap[21].
BSI AMT/8	BSI (British Standards Institution) is the UK National Standards body which is developing standards for AM under committee AMT/8.
CEN/TC 438	This is a technical committee within the European Committee with the aim to develop a series of standardisation deliverables in the field of Additive Manufacturing.
UNM 920	UNM, Union de Normalisation de la Mécanique, is the sectorial Standardisation Office of the French standardisation system in the field of mechanical engineering and rubber industries. UNM 920 is the committee on AM.

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[21] *Available at http://www.sasam.eu/index.php/press/sasam-in-magazines-english/viewdownload/9/176*

Involvement of international standards bodies in AM standards development (continued)

VDI	VDI is the association of German engineers which frequently publish technical standards.
AWS D20	American Welding Society develops standards for metal AM.
UL	UL is a global independent safety science company also working on safety standards for AM.
SAE AMS AM	This is a technical committee in SAE's Aerospace Materials Systems Group with the responsibility to develop and maintain aerospace material and process specifications and other SAE technical reports for additive manufacturing.

A2 Summary

AM as a relatively new technology is making rapid strides towards adoption as a flexible manufacturing technology. AM offers a number of advantages over the more established manufacturing technologies, most notably the opportunity to produce highly complex designs, reducing material wastage during the manufacturing process and accelerating the product development cycle. AM has the potential to simplify supply chains. The technology has shown consistent growth over the past 20-plus years, with the compound annual growth rate (CAGR) of worldwide revenue for all AM related products and services better than 25%. The CAGR for the period 2012 to 2014 is an impressive 33.8%[22]. Although still a small market compared to the conventional manufacturing market, it is developing a competitive advantage as a preferred manufacturing technology in those market sectors where high value low volume manufacturing is prevalent and where product customisation and time to market is a key success factor. It is encouraging to see that AM has also made significant strides in being adopted as a manufacturing technology for final part production, with more than 42% of all AM applications in 2014 geared towards final part production.

There is, however, significant opportunity for research and development programmes to advance AM towards a mature manufacturing technology. Applications in metal AM are lagging behind the use polymers and other non-metal materials in industrial applications. Although significant hype exists around the technology, there are a number of technical challenges that need to be addressed to ensure that AM reaches the manufacturing readiness levels required for serial production in those market segments where AM can have the biggest impact.

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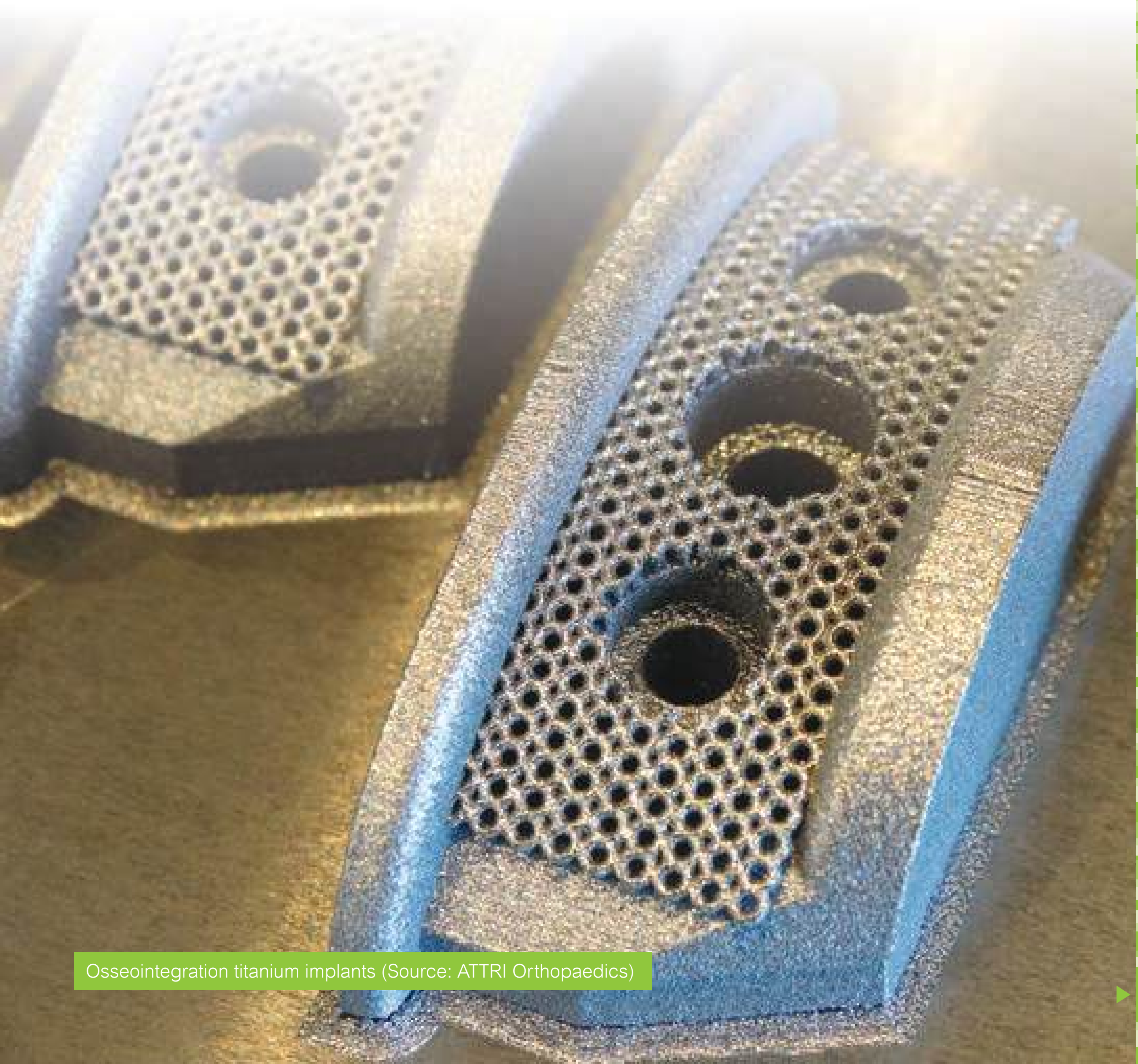
[22] *Wohlers Report 2015 – 3D printing and Additive Manufacturing State of the Industry*

Section B: Additive Manufacturing

The South African Landscape and Opportunities



Osseointegration titanium implants (Source: ATTRI Orthopaedics)

B1 Local research trends and capabilities

B1.1 Adoption of Additive Manufacturing in South Africa

South Africa's AM capabilities date back to the early 1990s when the technology was known as rapid prototyping (RP) and when there were only three RP machines in the country. The first machine was imported by 3D Systems (Pty) Ltd in 1990 which was followed by two machines that belonged to the CSIR. Rapid prototyping has since then established itself as a key technology in the rapid product development suite of technologies and over the past decade there has been a growing acceptance of this powerful technology, not only as a prototyping tool, but increasingly as disruptive manufacturing technology. The inherent ability of the technology to accommodate part complexity and customisation, coupled with an ever-increasing range of materials, has provided industry with unprecedented flexibility in design and production. Resulting from this, AM has replaced RP as the internationally accepted terminology for this technology.

An important driver of local acceptance of this technology has been RAPDASA. Since its inception in 2000, RAPDASA's primary objective has been to convince the South African industry of the importance of AM for maintaining international relevance and competitiveness. From the modest beginnings of RP/AM in the early 1990s in South Africa, the use of AM has grown at an unforeseen rate. Most of the rapid growth of the past few years is attributable to the uptake of the technology by industry. The progress of AM in South Africa was also enhanced by the recognition in the AMTS of its importance for improving the competitiveness of the South African manufacturing sector.

The advent of 'Personal 3D Printers' (P3DP) contributed to the boom in the South African AM industry. Following a staggering increase in total machine sales since 2010, 2012 closed with approximately 800 machines sold in South Africa with P3DPs accounting for two-thirds of these (Figure 10). The total number of AM machines grew by 85% in 2013 with the percentage of entry level machines increasing to about 78%. By November 2015 the total number of AM machines were estimated at 3,500 of which 87% were entry level machines. A recent analysis has also revealed that AM platform investment in South Africa has exceeded R380 million (approximately $30 million), with approximately 67% spent in the last two years. Most of these machines manufacture plastic or polymer parts with only nine of them falling in the metal AM category. Of these nine, six machines are used for AM and able to produce metallic components from, among others, titanium powder. The other three systems are locally produced direct energy deposition systems dedicated to refurbishment applications.

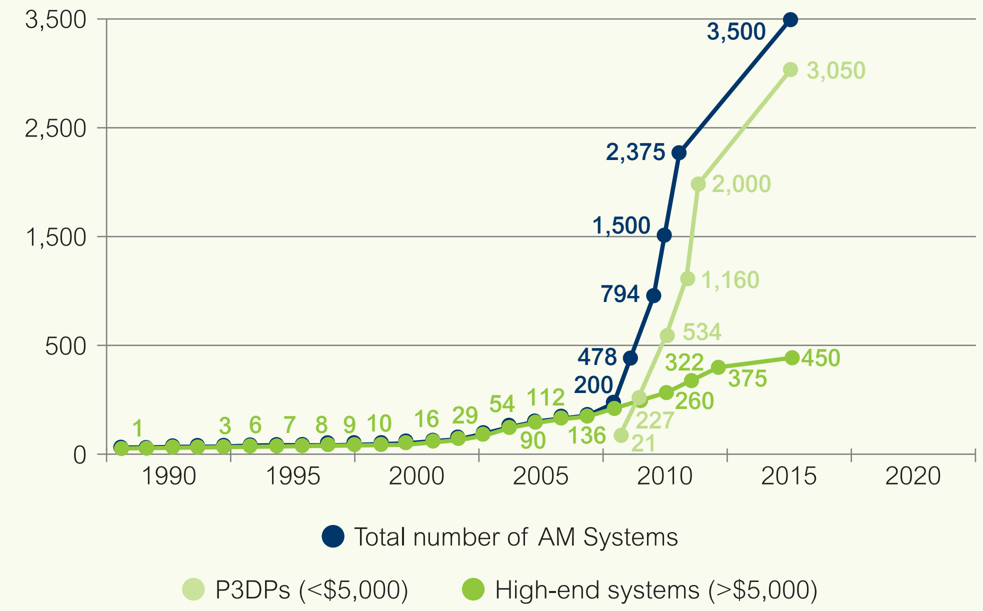


FIGURE 10: Growth of number of AM machines in South Africa until 2014 (Source: DJ de Beer, 21 September 2015)

South Africa is endowed with natural resources, including a high percentage of the global titanium mineral reserves. The South African Government's support of beneficiation and a parallel initiative in aerospace science and technology to increase the country's AM technology base, has created opportunities for metal-based AM technologies.

Another major stimulus for developing local AM capability was the significant government R&D grant to develop South Africa's first home-grown AM platform, Aeroswift. The Aeroswift high speed large area AM platform started as a feasibility study under the auspices of the Titanium Centre of Competence (TiCoC). The TiCoC was established as part of the light metals programme of the Advanced Metals Initiative. Based on local intellectual property, the Aeroswift project is a collaboration between South Africa's largest private aerospace manufacturing company, Aerosud Innovation and Training Centre (ITC), and the CSIR National Laser Centre. This development coincides with the Department of Science and Technology-funded development of a titanium powder production pilot plant, managed by the TiCoC, at CSIR Materials Sciences and Manufacturing.

These developments created the right climate for investments in several commercial metal-based AM systems at the Central University of Technology, Stellenbosch University and the NLC.

B1.2 Additive Manufacturing research landscape in South Africa

B1.2.1 Methodology

The results of a comprehensive survey of local public sector AM capabilities are presented in this section. The inputs are based on interactions with local AM role players and participants in the AM strategy development workshops and related events, as well as a focused survey questionnaire designed to obtain detailed information from the participants to map current capabilities in AM research. The scope of this survey included R&D focus, industry focus, infrastructure, facilities, manpower, certification status, etc.

Participants were requested to define their current resource allocation and maturity levels based on the following guidelines:

Resource allocation

- Subcritical: Low allocation of personnel/researchers and limited access to AM facilities or infrastructure;
- Emerging: Allocation of senior personnel or researchers and access to AM facilities or infrastructure;
- Building: Research chair and/or group with necessary infrastructure and manpower to carry out meaningful research; and
- Established: Established research chair and/or group with extensive AM facilities and dedicated manpower.

Maturity

- Proof of concept: Investigating potential of new processes and technologies;
- Technology development: Developing systems or processes for industrial applications;
- Prototyping: Development of prototype parts or systems for use by industry; and
- Manufacturing and sales: Production of components or parts.

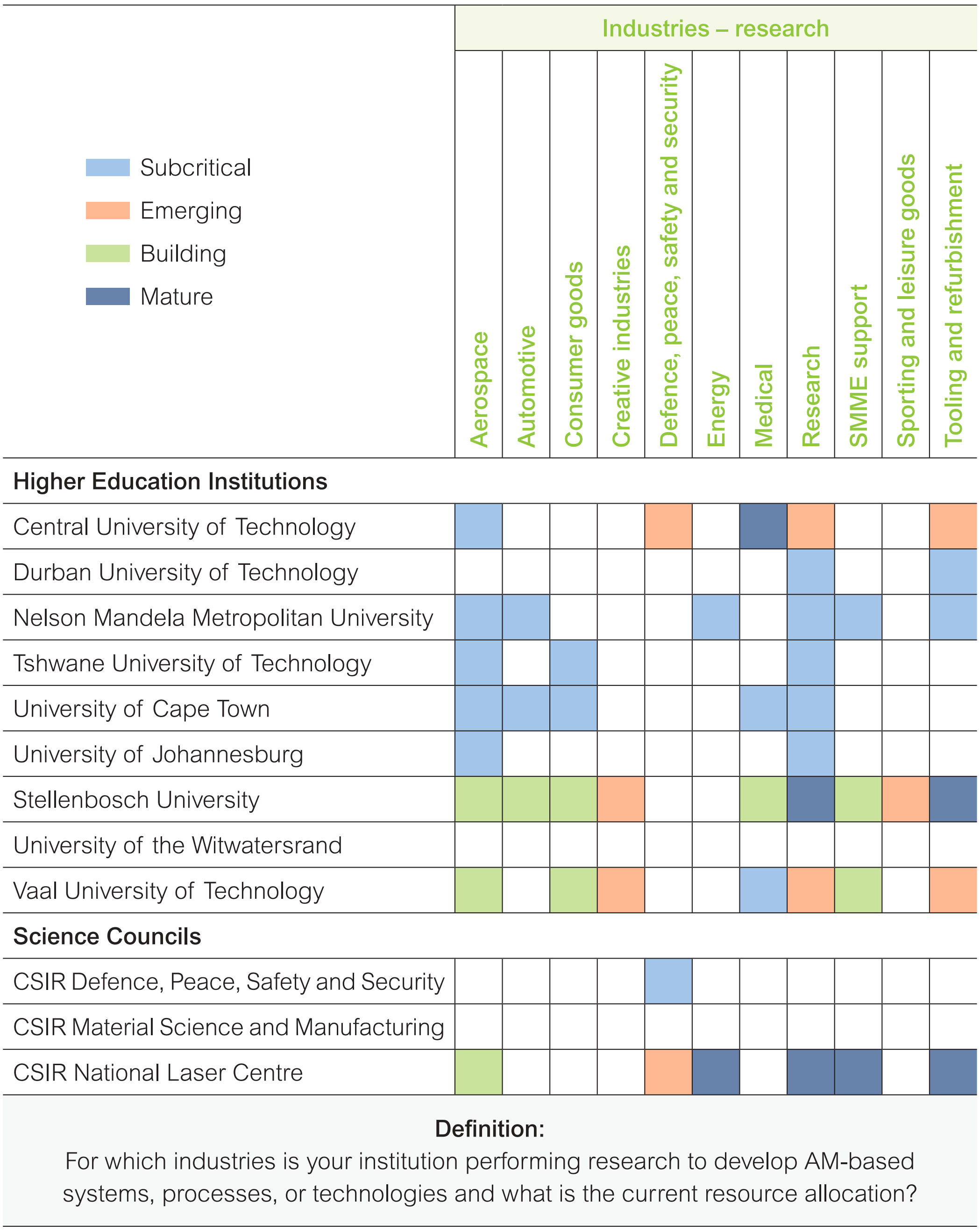
Active participants in this process included:

- **Higher Education Institutions:** Central University of Technology, Durban University of Technology, Nelson Mandela Metropolitan University, Tshwane University of Technology, University of Cape Town, University of Johannesburg, Stellenbosch University, University of Witwatersrand and the Vaal University of Technology; and
- **Science Councils:** The CSIR through its operating units the National Laser Centre, Defence Peace Safety and Security, and Materials Science and Manufacturing.

The team responsible for the strategy development critically reviewed inputs received, and validated the inputs received with the various institutions through a consultative process.

Although useful feedback was received from industry, the current industry sample has shown that the scope of the exercise needs to be expanded and refined to more clearly differentiate what is performed in support of R&D by industry versus its more routine prototyping and production activities.

The resultant capability matrix is provided in Figure 11.



🟦 Subcritical
🟧 Emerging
🟩 Building
■ Mature

	Industries – research										
	Aerospace	Automotive	Consumer goods	Creative industries	Defence, peace, safety and security	Energy	Medical	Research	SMME support	Sporting and leisure goods	Tooling and refurbishment
Higher Education Institutions											
Central University of Technology	🟦				🟧		■	🟧			🟧
Durban University of Technology								🟦			🟦
Nelson Mandela Metropolitan University	🟦	🟦				🟦		🟦	🟦		🟦
Tshwane University of Technology	🟦		🟦					🟦			
University of Cape Town	🟦	🟦	🟦				🟦	🟦			
University of Johannesburg	🟦							🟦			
Stellenbosch University	🟩	🟩	🟩	🟧			🟩	■	🟩	🟧	■
University of the Witwatersrand											
Vaal University of Technology	🟩		🟩	🟧			🟦	🟧	🟩		🟧
Science Councils											
CSIR Defence, Peace, Safety and Security					🟦						
CSIR Material Science and Manufacturing											
CSIR National Laser Centre	🟩				🟧	■		■	■		■

Definition:
For which industries is your institution performing research to develop AM-based systems, processes, or technologies and what is the current resource allocation?

FIGURE 11: Capability map detailing resource allocation to AM R&D and the industry focus of such efforts

B1.2.2 Number and type of commercial systems

The current number of commercial AM systems, as per the ASTM-defined AM process categories at South African public funded R&D institutions is shown in Figure 12.

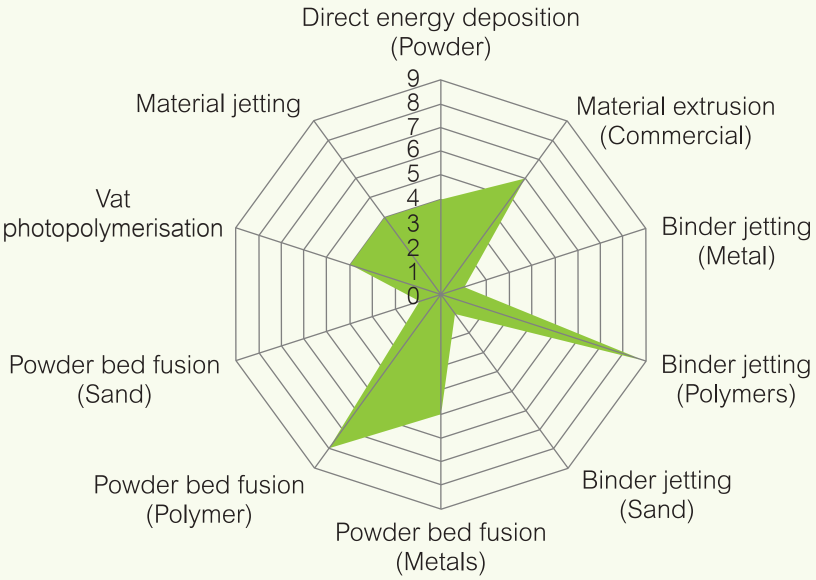


FIGURE 12: AM machines available at R&D institutions in South Africa

These results show the current predominance of polymer and resin-based AM systems with a total of 27 and 10 systems respectively being used at several Higher Education Institutions, science councils and service bureaus. This type of distribution is not unique to South Africa, with lower-cost polymer and resin-based systems being by far the largest number of systems sold worldwide. Only six metal-based AM systems are currently in South Africa with the Central University of Technology housing most of these. These systems represent the way forward for the beneficiation of South Africa's natural mineral resources like titanium and vanadium through the manufacturing of high-value aerospace and medical parts. There are also two sand-based AM systems and one ceramic-capable system that are being used to make moulds for the local casting industry.

B1.2.3 Industry sector focus at Additive Manufacturing research and development institutions

Figure 13 shows the research and manufacturing focus of Higher Educational Institutions and science councils in AM with regard to industry sectors. The three areas with the most research interest are aerospace, tooling and refurbishment, and medical. Much focus is also being placed on general AM research and SMME support with the aim of developing new technologies and processes. The latter are currently being funded by the SMMEs themselves but there is significant scope for improvement if AM Technology Stations can be established that can broaden the support base for SMMEs.

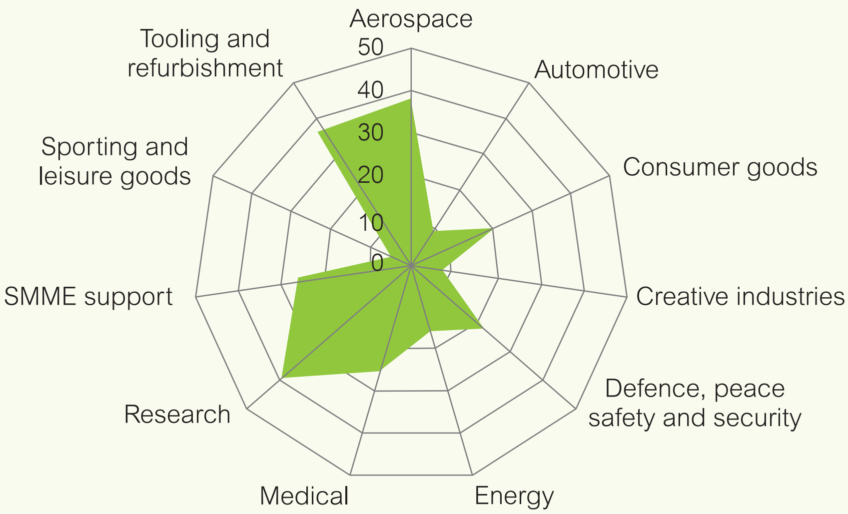


FIGURE 13: AM research maturity in identified industry sectors

The use of AM technologies across a spread of industries is encouraging. However, this use is focused mainly on prototyping and manufacturing of resin and polymer parts that have limited applications and potential. In addition, a large number of institutions are busy with under-resourced projects and are considered to be subcritical or emerging. If AM is to be a game-changer and make a significant impact on growth in the manufacturing industry, resource allocation to AM research needs to be increased.

B1.2.4 Focus of activity along research, development and innovation chain

Figure 14 shows the focus of AM along an RDI value chain within the AM community. The largest existing RDI competence is in post-processing and simulation. This involves development of heat treatment, hot isostatic pressing, machining, peening and polishing processes in the case of post-processing and material, mechanical, optical, and thermal modelling in the case of simulation. However, competence in the development of new materials, AM process and AM technologies development is not at the level necessary to ensure development of new processes and technologies to expand the AM industry. This would include development of new products and parts for aerospace and medical, as well as tooling and refurbishment. A noteworthy finding is the absence of significant R&D in electron beam direct energy deposition and materials research in polymers, ceramics and metal composites due to a lack of suitable equipment.

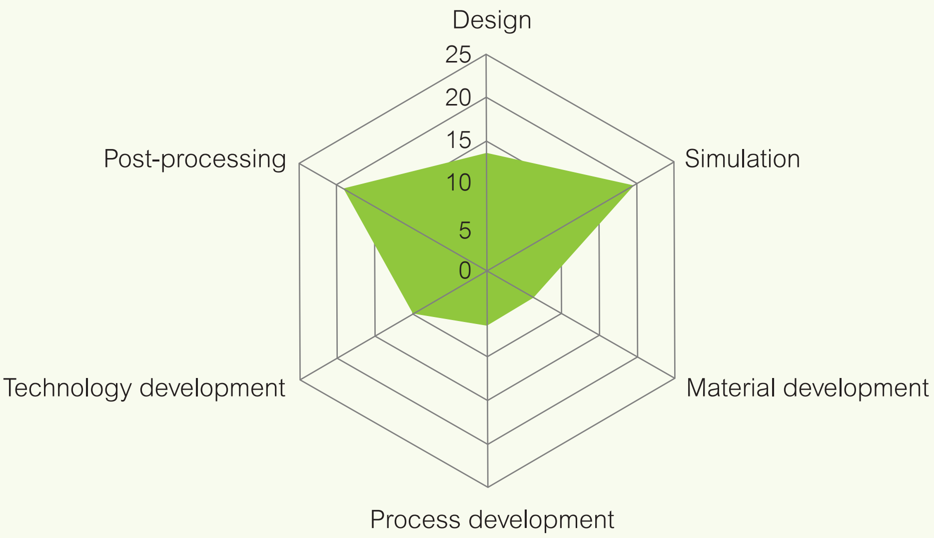


FIGURE 14: Resource allocation across the AM RDI spectrum at HEIs and science councils

B1.2.5 Testing and analysis

Figure 15 shows the maturity of the testing and analysis capabilities within the RDI community to support the AM production processes. Most aspects are covered with only a need to increase capacity in areas like CT scanning and environmental testing.

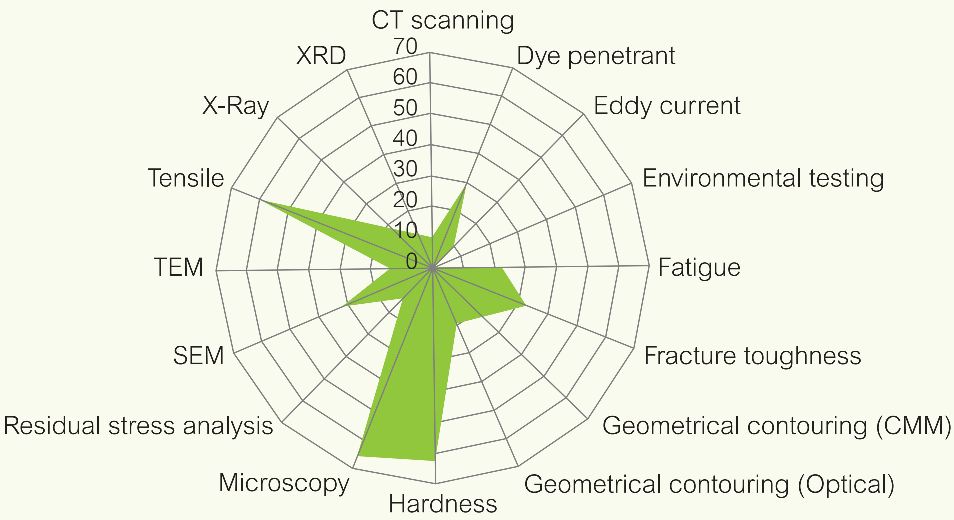


FIGURE 15: Maturity of the testing and analysis capabilities

When these surveys were conducted in 2014/15, there were approximately 70 fulltime researchers working at Higher Education Institutions and science councils in the field of AM. 75% of these were at Higher Eduction Institutions. There were also approximately 60 fulltime students and interns working in the field and ~ 20 technicians.

B2 Local opportunities in industry

There are numerous local opportunities to extend or introduce the use of AM in South Africa, as described in this section. This selection of opportunities is guided by (1) the stakeholder workshops, (2) international trends and (3) local capabilities. These opportunities are described here in broad terms and are defined at a more specific level in the next section, where they are also rated in order to arrive at priority focus areas. More information on the methodology followed to develop the focus areas is presented in Section C and Appendix A, and information on the consultative process followed is discussed in Appendix A.

B2.1 Aerospace and military

South Africa has an established aerospace industry and companies such as Aerosud, Adept Airmotive, Denel Aviation and Dynamics and Airbus DS Optronics have adopted AM technology as manufacturing technology for final parts, or have used the technology in prototype development as well as speeding up the product development cycle. With respect to commercial aerospace manufacturing, collaboration agreements are in place with customers such as Boeing and Airbus regarding the development of AM processes in South Africa. Titanium is a material that is of particular interest to both aeronautic and military applications because of advantages in weight and chemical resistance. South Africa has mineral resources, as well as world-class experience in the production of titanium parts. Examples of South Africa's expertise in working with titanium in AM can be found in projects completed at the Central University of Technology's Centre for Rapid Prototyping and Manufacturing (CRPM) and the Aeroswift project hosted at the CSIR National Laser Centre.

Locally produced AHRLAC aircraft with some components produced by AM technology (Source: AHRLAC and VUT)

B2.2 Medical and dental

Mandibular frame (Source: CRPM, CUT)

The use of AM in the medical industry is growing rapidly. Medical implants, medical devices and prosthetics can benefit a patient because they can be made to custom fit the individual. In the medical industry, AM includes not only the printing of synthetic implants and prosthetics, but also the exciting and fast-growing field of bio-printing and tissue engineering. These areas have the potential for substantial growth over the coming decade. A number of facial implants have already been developed, manufactured and implanted in South Africa with the use of AM technology.

The dental industry is another international market where AM is used extensively. Very little information is available for the uptake of this technology in the local market although it is a significant market internationally. Since 2005, AM has been used for producing crowns, bridges, dentures and moulds for the dental market. Original equipment manufacturers (OEM), such as EOS, have recognised the market potential in the dental industry and developed dedicated AM machines for this industry. By 2013 there was already in excess of 60 dental systems installed worldwide, producing 6.8 million dental units annually[23].

Partial denture manufacturing stages (Source: EOS)

B2.3 Role in traditional manufacturing

South Africa still has a large traditional manufacturing industry, and AM can play a positive role in this industry, particularly in accelerating product development and tooling processes. Despite the disenchantment that grew in the late 1990s with rapid tooling, South Africa has been one of the leaders in the past decade in the development of AM tooling for injection moulding. This includes hybrid tooling, where the cavity side of a mould is manufactured by high-speed machining and the core side is made by AM. South Africa has also advanced in the manufacture of expendable moulds for sand casting and investment casting. This is an

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[23] *http://www.eos.info/press/press_releases/2013_120313_2*

area in which South Africa could benefit by making its existing manufacturing facilities more efficient, flexible and responsive.

By using AM for the production of sand moulds or lost-pattern-investment-casting models it is possible to also produce complex designs or designs in which part design optimisation has been done. A case in point is the part shown in the figure on the right, which is often used to explain the benefits of part optimisation and design for AM.

Example of topology optimisation
(Source: LZN Laser Zentrum Nord GmbH)

B2.3.1 The tooling industry

AM technology offers significant opportunity for accelerated tooling development as well as tooling performance enhancement. In *injection mould tooling* as well as high-pressure die casting AM technology allows incorporation of features in a die/mould/insert not possible to machine with current machining approaches and technology. One such example is intricate conformal cooling channels incorporated in the design and manufactured by AM. The tool lifetime as well as throughput of an injection moulding tool can be improved by refining the cooling design of the tool. This is realised by introducing shaped cores, internal cavities or internal cooling channels to assist with heat load management of the tool. AM technology is ideally suited to manufacturing tooling with complex internal structures. Printed tools will have similar mechanical properties as tools machined from wrought material. Conventional machining and polishing techniques can be used to finish the tool to specification. Tooling performance improvement in small tools with conformal cooling channels has been demonstrated to have a significantly higher throughput than tooling using conventional cooling technology.

The South African footwear industry, valued at more than R5 billion and predicted to double in size over the next five years, is a good example of a traditional manufacturing industry that can benefit greatly from the flexibility and speed offered by AM for new tooling development. The AM facility at the Vaal University of Technology is using AM to rapidly produce moulds for shoe lasts, soles and conceptual designs for entirely new products. New designs and physical parts can be produced in days. AM is most relevant in accelerating the design process in today's shoe

Model of shoe printed with acrylic plastic powder, using coloured chemical binder (Source: Rapid3D) industry, and in future will be used for the actual production of shoe soles as better elastomeric materials become available. Already, Nike and New Balance offer high-end football and track shoes with cleat plates that are made by AM.

AM can also be used for the production of complex *tooling inserts*. AM makes it possible to manufacture a small insert containing complex detail which can be replaced if damaged without having to refurbish or remanufacture the complete tool.

Examples of tooling inserts and conformal channels produced using AM
(Source: Product Development Technology Station, CUT and Stellenbosch University)

B2.3.2 The casting industry

The developmental phase of a new product development process is the ideal place to exploit the advantages of AM as designs can be changed quickly and at a much lower price compared to conventional methods.

In *investment casting*, AM technology allows for sacrificial parts with very thin walls. Complex designs can be produced which would not be possible with conventional methods of investment casting.

AM technology can radically change the foundry industry by applying this technology to *sand casting*. Having the ability to produce high complexity sand moulds and cores with no tooling can reduce costs, increase savings and speed up service delivery. This is of particular importance

Aircraft engine development
employing AM technologies
(Source: Adept Airmotive)

for new product development as changes to geometries are done without high tooling costs. However, there is still very little buy-in from the foundries in South Africa to use this technology and industry buy-in will be essential to maintain a competitive edge internationally.

B2.3.3 Refurbishment

AM not only provides opportunities for the generation of new components, but is ideally suited for the refurbishment of high-value components and infrastructure. Directed energy deposition can be used to repair previously unserviceable parts and to enhance the performance of parts produced with traditional methods. Refurbishment using AM can also provide cost and productivity advantages in very demanding applications. In many cases, the laser-based process is superior to other surface engineering technologies such as thermal spraying, where adhesion properties can limit the impact and fatigue performance of repaired components, or submerged arc welding technologies, where high heat input processing can lead to distortion of the work piece.

Laser-based refurbishment
(Source: CSIR National Laser Centre)

The CSIR National Laser Centre has intellectual property and technology in the field of refurbishment relating to process application as well as specially designed alloys, creating opportunities for the development and industrialisation of this technology in South Africa.

B2.4 Automotive industry

AM is used extensively in the automotive market internationally and the use of the technology locally can improve the efficiency and competitive advantage of the South African automotive industry. Several large international car manufacturers have their own AM machines but are not using the technology in South Africa to its full potential. AM opportunities in this industry includes:

- Prototyping to reduce development time and improve efficiencies;
- Tooling development; and
- Tooling manufacture and jigs.

Other opportunities in the automotive industry include refurbishment of previously unserviceable tools and even production of final parts for high-end or custom vehicles.

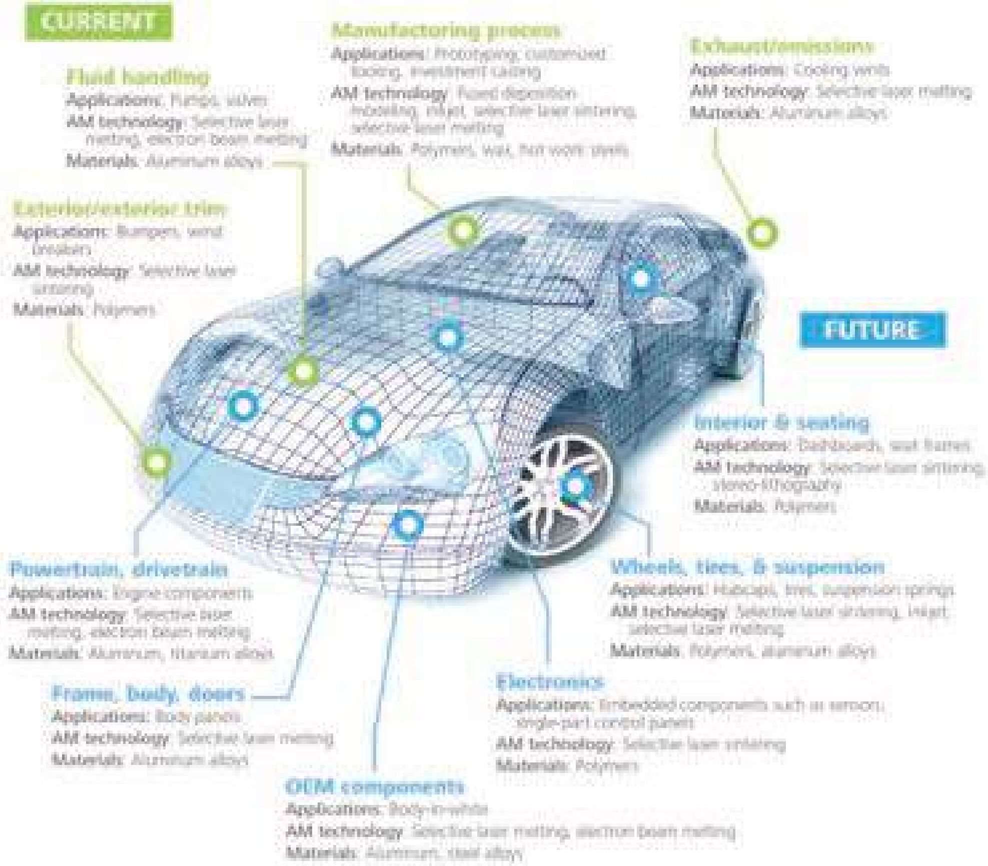


FIGURE 16: Present and future AM applications in the automotive industry (Source: Deloitte University Press)

B2.5 Materials development

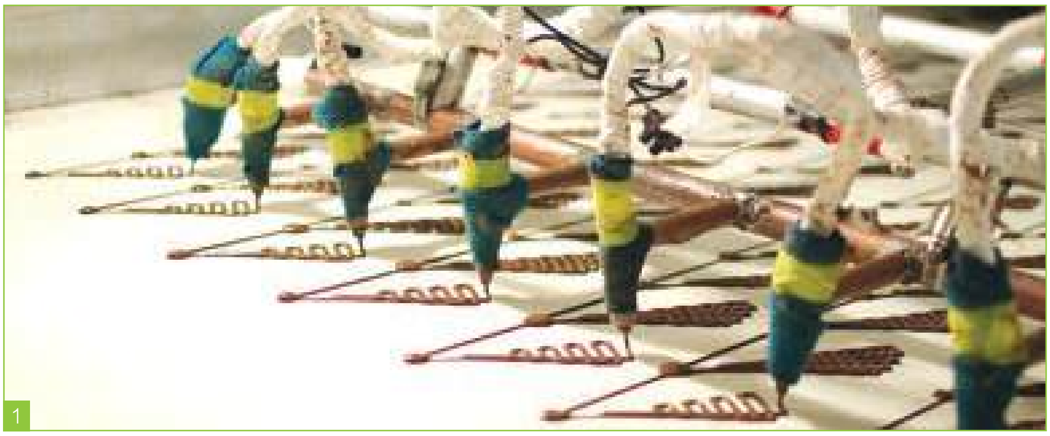
Titanium powder

A growing interest in metal AM has been observed in recent years. In South Africa, the national strategy to establish a titanium metal industry in the country, with the Titanium Centre of Competence as the implementation vehicle, has identified AM of titanium, along with the other technologies such as local production of titanium powder, powder consolidation into sheet, as well as other manufacturing technologies as key focus areas to support this strategy. The local production of titanium powder therefore presents a viable opportunity for local value addition through AM. This is especially true when one considers that approximately 30% of the minerals used to produce the world's titanium are currently mined in South Africa, and that finished titanium parts are imported into the country at 100 times the price of the raw material that is exported. Furthermore, Sasol is a large producer of polymers and a potential opportunity exists to develop materials (powder and filament) for the polymer AM market.

B2.6 Machine platform development

B2.6.1 Local development of low-cost 3D printers

The introduction of so-called ‘low-cost 3D printers’ has changed the face of the global AM market since they were introduced in 2008. These printers, loosely defined as 3D printers costing less than $5,000, have emerged after the expiration of some of the initial 3D printing patents. The printers are all desktop type printers and are extensively used by hobbyists and enthusiasts around the world.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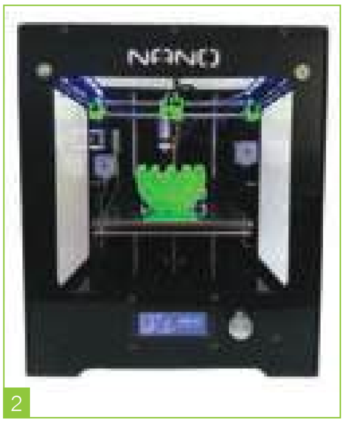

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3


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5


6

Source:
1. Fouche 3D Printing
2. Netram Nano
3. RoboBeast
4. Quentin Harley Morgan 3D printers
5. Fouche 3D Printing
6. Open Hardware

Various locally developed lower-end 3D printing systems

The international market for low-cost 3D printers is growing at a remarkable speed and in 2014, over 104 000 printers were sold (Wohlers, 2015). A similar growth in low cost printers is seen in South Africa, based on the data gathered by Prof. Deon de Beer and referred to in section B 1.1. Based on the lapsing of key patents in fused deposition modelling (FDM) and the public interest in the technology, an increase in locally developed printers are seen. This is potentially a very significant market for South Africa. Not only does an opportunity exist for the development of AM technology, but also for applications, material development, software development, new business cases and education using low-cost printers. Understanding how these low-cost printers can be used in support of more traditional manufacturing processes is important. A number of 3D printers have already been developed in South Africa, including the repRAP Morgan, Nano 3D printer (Netram Technologies) and RoboBeast machines.

B2.6.2 Local development of high-end systems

The use of AM technology to produce final parts (as opposed to prototypes) has increased substantially in recent years. However, this growth is still limited due to the capabilities of current commercial AM systems. There is a significant opportunity for the development of systems that will address these limitations.

Aeroswift is a locally-developed technology that is addressing certain of these limitations. The development is aimed at producing a system that will enable high-speed manufacturing of metal parts. The design also accommodates a large build volume of ~2 m x 0.6 m x 0.6 m, allowing larger parts that present commercial systems, or batch manufacturing. A substantial increase in forming rate is achieved through implementation of a high-power laser in the system.

Locally developed Aeroswift system (Source: Aerosud ITC and CSIR National Laser Centre)

B2.7 Small, medium and macro enterprises sector

Although the application of high-end AM systems has been limited mostly to prototyping, there are many instances where innovative SMMEs are using AM in their production processes. There are numerous high-end AM systems installed in South African companies, being used for a wide range of applications.

There are also some surprising success stories where businesses are successfully using ‘entry level’ hobby or consumer printers for low volume production. Some examples include low volume production of filter end caps and drone components.

Information from local SMMEs and agents for AM systems confirms that industry would benefit by having access to higher-end systems. At present SMMEs and industry players are hesitant to invest in expensive high-end systems, or they do not have the funds to acquire these systems. This results in either not adopting the technology, or acquiring lower-end specification systems which ultimately results in inferior products and disappointment. Mechanisms such as a technology development and demonstration centre with the mandate to support industry can address this entry barrier.

The following industry sectors are mainly addressed internationally through the SMME environment:

B2.7.1 Jewellery

Internationally, AM has had a large impact on the jewellery industry. AM is very successfully used to produce jewellery moulds. This is particularly evident where CAD is becoming a tool of choice for the design of jewellery. There are even AM systems available that can print using materials such as gold which allows for direct manufacturing of jewellery.

Jewellery pattern and final product
(Source: Rodney Chandler)

South Africa has a substantial jewellery industry and there is already a vibrant SMME industry incorporating AM technologies in the manufacturing of jewellery. This sector is seen as a high priority sector given the local relevance and resources that can service this sector. However, concerns exist about the lack of equipment being utilised in this industry in South Africa. This is an industry that has seen decline in the number of manufacturers in recent years and can benefit enormously from government assistance in the implementation of AM technologies.

B2.7.2 Prosthetics

AM techniques can have a huge impact in the field of prosthetics in terms of cost reduction, customisation and design complexity. The three major focus areas for AM prosthetics in South Africa are the following:

- **Low-cost prostheses:** There is currently a huge demand or back-log for cost-effective, high-quality prosthesis solutions in the low income market in South Africa. The majority of state-funded hospitals have waiting lists of up to five years for prostheses. This market can be satisfied with current cost-effective manufacturing methods to provide low-cost prosthetic parts and components for the low income group;
- **High-end prostheses:** Internationally, there is a large drive to reduce the cost of individualised high-end prosthesis using AM; and
- **Cosmetic prostheses:** Prostheses have become a fashion accessory and the trend is to customise prostheses to the liking of the amputees. Initiatives, locally and abroad, have been established to satisfy this market.

Interestingly, desktop 3D printers featured regularly in the media over the past year for their use in the production of very low-cost prosthetic fingers and hands, with some of this work pioneered in South Africa. The use of such low-cost technologies has clear benefits for developing communities in South Africa.

AM techniques are the future to manufacture personalised prostheses for the patient's needs. This can be achieved as the manufacturing costs continue to reduce, and the scanning and design equipment becomes more accessible and cost-effective.

Locally developed prosthetic devices (Source: Robohand)

B2.7.3 Audiology

Globally, hearing aids are seen as one of the early success stories for using AM. The shells of the hearing aids are being manufactured through AM in the international market on a commercial scale. If a feasible market entry strategy could be developed, South Africa could also apply AM technology in this field.

B2.7.4 Other application areas

B2.7.4.1 Archaeology

Much of South Africa's cultural and archaeological heritage is made out of relatively fragile and non-permanent materials such as clay, wood and bone. AM could play a role in helping to preserve some of this heritage in a more permanent medium. A number of 3D scanning technologies are now available that allow objects to be digitised so that their physical shape, and even colour, can be preserved. From this digital description, it is possible to 3D scan and then 3D print the artefacts to create relatively low-cost physical embodiments of irreplaceable objects. Work has even been done on using similar materials to those of the artefacts, such as 3D printing in clay and ceramics, to ensure a reproduction as faithful to the original as possible.

B2.7.4.2 Creative arts

The design freedom offered by AM is appreciated widely in the creative arts industries as this eliminates many of the barriers to manufacturing. AM is used in many fields including art, fashion, décor and jewellery to name but a few. Specifically, the design and manufacture of fashion shoes and clothing has received media attention recently.


The Horse Marionette
(Source: Nomili, Michaela Janse van Vuuren)

Related to AM, a number of South African designed pieces have been acclaimed internationally. Notable is the work done by Nomili, with artwork displayed internationally.

B2.7.4.3 Retail and online printing bureaus

Internationally, online printing bureaus are already an established, well-known and highly profitable enterprise. More recently, 3D printing retail stores have started to open in cities all over the world. There is a real potential for SA to launch initiatives like this. These initiatives are not just profitable, but are also very effective marketing tools by creating a general awareness in the public and by attracting media attention.


Example of factory model produced at 3D printing bureau (source: Rapid3D)

A list of known 3D print bureaus is presented in Appendix C.

Section C: South African Additive Manufacturing Strategy

Casting pattern printed in sand (ADEPT RP Pattern) (Source: Airmotive Technology (Pty) Ltd)

C1 Priority focus areas and enablers

C1.1 Identification and selection of opportunities

The South African Additive Manufacturing Strategy is focused on the development of niche areas to take advantage of high-priority opportunities that can contribute towards South Africa's socio-economic imperatives. In order to have a positive impact on South Africa's economy, these focus areas were developed based on a set of drivers that was identified for the South African market and which takes advantage of:

- South African RDI capabilities;
- South African natural resources; and
- Local markets.

Various opportunity areas for South Africa in the field of AM manufacturing were identified through three national workshops. This input was supplemented by identifying opportunities through analysing local AM capabilities and evaluating international trends.

The opportunities were prioritised using an evaluation process involving a panel of experts who rated the opportunities against criteria covering the two main considerations of 1) 'attractiveness', which covers need, as well as the value and potential of the opportunity, and 2) 'strategic fit', which covers national capability, alignment with national objectives, as well as the likelihood of realisation. This process is illustrated in Figure 17.

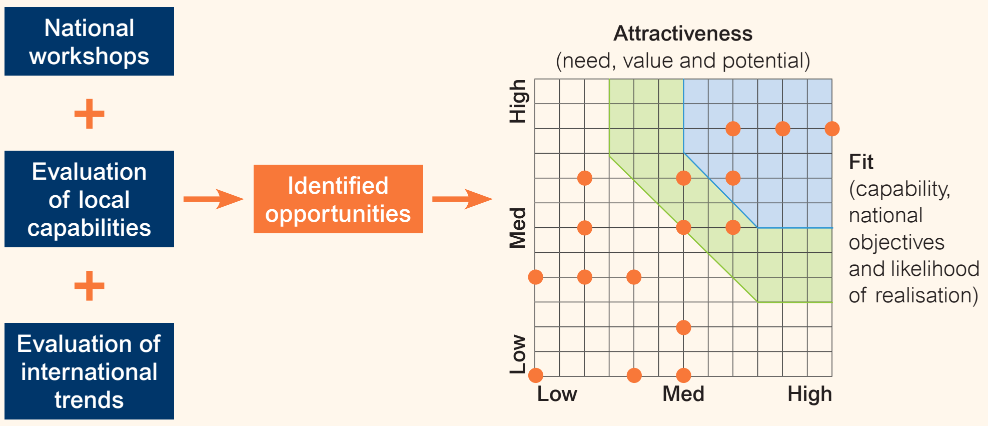


FIGURE 17: Opportunity identification and prioritisation

The main opportunities for South Africa in the field of AM were identified as follows:

High priority opportunities

- Production of medical devices and implants;
- Production of parts for the aerospace industry;
- Refurbishment of parts and tools for the automotive and other industries;
- Impact on the local footwear industry through AM tooling and prototyping;
- Raw material development for AM processes;
- Development of high-end AM systems; and
- Development of low-cost 3D printers.

Medium priority opportunities

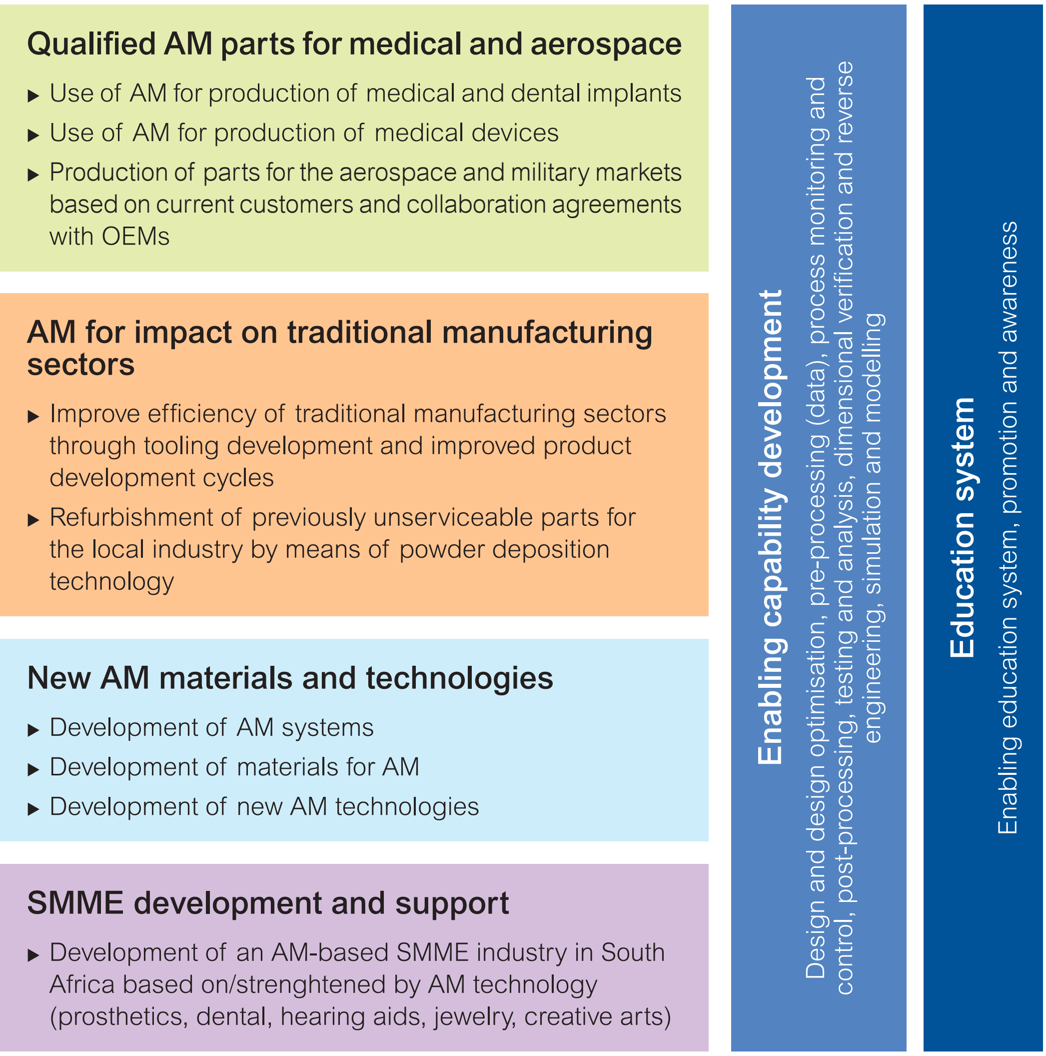
- Production of prosthetics;
- Production of crowns and bridges for the dental industry;
- Production of customised hearing aids;
- Manufacture of jewellery; and
- Use of AM in the creative arts industries.

Other opportunities which are currently considered as low priority areas for South Africa include the production of:

- Low-cost rocket engine combustion chambers;
- Replacement parts for household appliances;
- Replacement parts for old vehicles;
- Customised packaging for the food industry;
- Customised packaging for high tech products;
- Architectural elements;
- Final parts for the automotive industry;
- Pre-assembled robotic components;
- Consumer goods e.g. cell phone covers; and
- 3D scanning and printing of archaeological artefacts.

C1.2 Discussion of focus areas

The rated opportunities were extensively evaluated by AM experts and these inputs were used to develop specific focus areas for South Africa to guide public and private sector investment in AM RDI in South Africa. These focus areas, which are summarised in figure 18, form the basis of the South African Additive Manufacturing Strategy.



Qualified AM parts for medical and aerospace

- Use of AM for production of medical and dental implants
- Use of AM for production of medical devices
- Production of parts for the aerospace and military markets based on current customers and collaboration agreements with OEMs

AM for impact on traditional manufacturing sectors

- Improve efficiency of traditional manufacturing sectors through tooling development and improved product development cycles
- Refurbishment of previously unserviceable parts for the local industry by means of powder deposition technology

New AM materials and technologies

- Development of AM systems
- Development of materials for AM
- Development of new AM technologies

SMME development and support

- Development of an AM-based SMME industry in South Africa based on/strenghtened by AM technology (prosthetics, dental, hearing aids, jewelry, creative arts)

Enabling capability development

Design and design optimisation, pre-processing (data), process monitoring and control, post-processing, testing and analysis, dimensional verification and reverse engineering, simulation and modelling

Education system

Enabling education system, promotion and awareness

FIGURE 18: Opportunity grouping into focus areas

In figure 18 the key industrial focus areas are captured in the horizontal layers, while the cross-cutting supportive activities are shown in the boxes to the right of the industrial focus areas.

C1.2.1 Qualified AM parts for medical and aerospace

Over the past four to five years, AM has progressed from a prototyping technology to produce demonstrator or sample parts to a manufacturing technology that has the ability to produce fully-functional final parts. In 2014, 42.6% of AM products and services revenue globally were derived from the production of final parts for a wide variety of market sectors.

Osseointegration Ti implants
(Source: ATTRI Orthopaedics)

South Africa has large mineral reserves of titanium bearing minerals and vanadium compared to the rest of the world. The availability of these ores, combined with the expertise and R&D infrastructure available at South African R&D institutions provides an opportunity to develop processes for applications in the medical implant and devices market, as well as the aerospace manufacturing markets. South Africa has a growing aerospace manufacturing industry which is well positioned with respect to international aerospace manufacturers and creates a significant opportunity to establish a strong AM-based manufacturing industry in titanium-based components.

Mandibular frame Ti implants
(Source: CRPM, CUT)

Vision

The vision of this focus area is advanced AM technology established in South Africa which has positioned the local industry as a leading supplier of metal and non-metal AM-produced parts, with a specific emphasis on qualifying AM processes for final part production in the medical and aerospace markets.

Stator ring in IN718
(Source: Morris)

For realising this vision, technology development programmes are required to industrialise AM technology to higher technology readiness levels (TRLs) for challenging applications. Due to the opportunities that medical devices and implants, as well as aerospace, offer with respect to customisation, high-value applications, performance requirements, as well as design optimisation requirements, these two application areas are ideal opportunities to focus the industrialisation of AM processes towards TRL 8 and 9. Knowledge gained and technology produced within this priority focus area is expected to spill over to other applications areas such as automotive and marine.

Drivers

- Design freedom;
- Optimised designs;
- Weight reduction in parts;
- AM-produced parts with high build integrity (mechanical and fatigue-related properties);
- Optimal material utilisation; and
- Beneficiation of local resources.

Objectives

- Development of fundamental process knowledge in metal and non-metal AM to support the establishment of qualified processes for the production of parts for the medical and aerospace markets, as well as support the development of locally produced AM technology platforms;
- Advance AM of both polymer and metal parts, to deliver batches of complex parts in quantities that do not accommodate amortisation of tooling costs, or even single numbers of customised products;
- Qualification of the processes for AM-produced medical implants and devices; and
- Qualification of the processes for AM-produced commercial non-structural and structural aerospace applications in a range of materials.

Outcomes

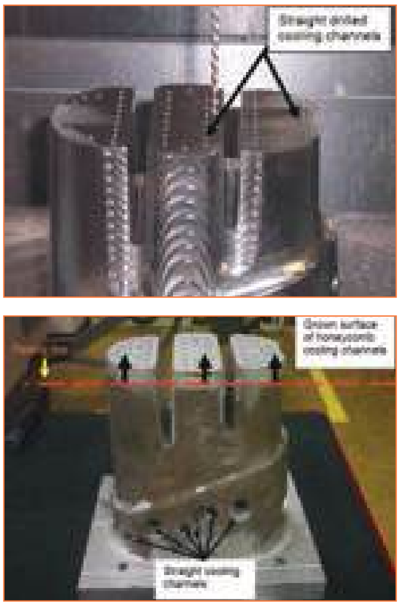
- In the short term, South Africa to produce components for the aerospace market (forecast production of up to 12 tonnes per year by 2019);
- In the longer term, South Africa to be a major producer of AM products to the aerospace industry. Exports of more than 50 tonnes of titanium AM parts annually with large scale production in other materials such as aluminium and inconel;
- 300 new jobs created in metal AM, with indirect job creation of up to 1,050 (3.5 multiplier) by 2024; and
- Six new SMMEs created that provide metal AM services and products to industry.


Valve body (Source: AHRLAC)

C1.2.2 Additive Manufacturing for impact in traditional manufacturing sectors

Not only is AM used for the direct production of parts in new or emerging industries, but the technology is also used to support and improve existing manufacturing sectors. In traditional manufacturing, materials are shaped and formed using processes that involve cutting, forming and joining technologies. These technologies are in most cases dependent on tooling that is used in the processing of materials to produce the final product.

By using AM in the manufacturing development process chain, it is possible to reduce the lead-times to produce the final tooling, as well as create opportunities for customisation of tooling by manufacturing customised tooling inserts.



Conformal cooling channels in plastic injection mould tooling (Source: A. Moammer, Stellenbosch University)

Hybrid manufacturing, where AM-based technologies are combined with more traditional manufacturing technologies to produce tooling designs with superior performance characteristics, is also increasingly being used in production processes. AM allows the tool designer to design and produce more complex tooling with intricate cooling channels with better cooling performance that allows higher production throughput due to reduced cycling time. In addition, the hybrid manufacturing process allows for larger cost savings compared to when the tool is produced through AM processes alone. Through material build-up, AM also lends itself to the repair of existing tooling and components which are damaged or which do not meet operational specifications due to wear and tear. In 2013 tooling-related applications amounted to 27% of all AM applications.

Tooling insert (Source: Product Development Technology Station, CUT)

The direct tooling market in South Africa amounts to an estimated R13 billion[24], with an additional R2 billion for maintenance and servicing in the tooling industry. The tooling industry is an important industry segment; it supports key manufacturing sectors such as the automotive, aerospace, consumer goods, packaging and electronics sectors. Applications of AM in tooling is on the increase, with examples of tooling used in casting, forming and machining processes, as well as for use in assembly jigs and fixtures. In health care there are examples of medical guides produced with AM.

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[24] *http://www.tasagauteng.co.za/*

However, the tooling industry in South Africa is on the decline due to low investment from the private sector and government, technology stagnation, skills losses and increasing imports. The opportunities that AM offers with respect to innovation in tooling design, reduced lead times resulting in shorter time-to-market, cost savings due to better performing tools and improved quality and shorter lead time for tool repair, can all contribute to the rejuvenation of South Africa's manufacturing industry and increase the country's ability to compete globally. Focused programmes to support skills transfer from experienced pattern makers to the next generation of tool designers are required. There is already strong capacity within selected R&D institutions in South Africa with respect to AM for tooling applications as well as refurbishment applications. This can be further strengthened through investments in R&D programmes focused on AM for the traditional manufacturing sector.

Vision

The vision of this focus area is advanced AM technology established within the traditional manufacturing technology sector that positions the local industry to save on tooling costs, to assist the industry to provide new products to market more quickly, as well as to support industry to reduce maintenance, repair and overhaul budgets through the development of AM-based refurbishment technologies.

Laser Metal Deposition technology for refurbishment of high value components
(Source: CSIR National Laser Centre)

For realising this vision, technology development programmes are required to support tooling-related programmes in AM technology and progress the applications of AM in the traditional manufacturing sector to higher TRL levels.

Drivers

- Accelerated product development cycle;
- Cost savings due to increase in tooling life and faster production cycle;
- Reduced down time;
- Customisation opportunities; and
- Improved functionality.

Objectives

- Development of tooling applications with the objective of demonstrating how AM can result in reduced capital investment to achieve economies of scale and increased flexibility;
- Development and qualification of AM processes for the manufacturing of tooling and tooling inserts for various market applications;
- Establishment of expert software systems that can guide tooling end-users to provide specifications for tooling produced with AM;
- Establish and strengthen competencies in digital design and production of moulds and dies for injection moulding and die casting, including process planning and techno-economic modelling; and
- Development of AM technologies for utilisation in the repair and refurbishment of tooling, as well as high-value components and infrastructure in the aerospace, automotive, agriculture, power generation, marine, mining and petro-chemical industries.

Outcomes

- AM of foundry moulds and tooling adopted in selected foundries at shop-floor level. Capacitate local foundries for production of designated components (e.g. valves and pumps) to participate in the localisation strategy;
- Increase local manufacturing of consumer goods through acceleration of representative product development processes, as well as the incorporation of soft AM-produced tooling. An example is that of the footwear industry where the target is to increase local manufacturing of shoes from 30% to 45% of local consumption in five years and up to 70% in ten years; and
- Increase the local manufacture of foundry products from 1% to 3% of BRICS outputs by 2024.

C1.2.3 New Additive Manufacturing materials and technologies

Internationally, R&D programmes in AM are focused on maturing the technology for industrial applications. Factors that still limit the full adoption of AM as a manufacturing technology include production costs, quality and integrity of the AM process, size constraints, processing speed constraints, availability of high quality materials, range of materials that can be used in AM and real time process control to ensure high integrity builds.


Ti powder pilot plant (Source: CSIR)

Initiatives already exist in South Africa in support of new material and AM technology development to address some of these limitations. South Africa has the world's 2nd largest reserves for titanium bearing minerals and 3rd largest for vanadium reserves. These metals, once extracted from the mineral ore, are key for high-end industry applications such as medical implants, aerospace components, as well as applications in the marine and chemical processing environments. South Africa has developed and patented a technology to continuously convert titanium tetrachloride feedstock into pure titanium powder. It is anticipated that the locally developed titanium powder material will have a significant cost advantage, which can drive down the production costs of components manufactured using this metal.

South Africa also has a strong petro-chemical industry that produces polymers as a by-product of the synthetic fuel production process. South Africa has a competitive position in the global polymer industry and particularly the production of polymer powders. These materials can potentially be developed into powders for polymer AM processes with a focus on more affordable high-quality feedstock for AM.


Locally designed Aeroswift system (Source: CSIR National Laser Centre & Aerosud ITC)

The work performed at the CSIR in collaboration with Aerosud ITC has proven that the country has the ability to develop new AM technology platforms addressing present limitations in commercial systems. The Aeroswift platform and spin-offs from this technology have the potential to position South Africa as a leader in high-speed powder fusion AM technology.

Similarly, the market demand for low-cost 3D printers provides an opportunity for developments to improve and commercialise low-cost printers.

Vision

The vision of this priority focus area is South Africa positioned as a technology leader in materials and technology platform development in niche AM markets. This priority area will focus on the development of high-end systems that will differentiate South Africa as a leader in high-speed AM technology, as well as in materials for AM, based on locally available materials.

For realising this vision industrialisation programmes are required to increase the TRL level of the high end as well as low-cost systems under development, as well as to support programmes in materials development.

Drivers

- Increase part size;
- Increase production speed;
- Reduce manufacturing cost;
- Improve build quality; and
- Increased used of local resources.

Objectives

- Industrialisation and commercialisation of South Africa's high-speed large-area AM platform for metal AM, Aeroswift;
- Development of materials for AM for metal and non-metal applications, capitalising on the abundant local titanium and vanadium resources, as well as the evaluation of polymer-based by-products from the petro-chemical industry sectors;
- Drive a programme for the establishment of low-cost 3D printing solutions to advance local training and public understanding programmes;
- Developing the functionality and application of low- to medium-cost printers for use within the SMME sector and understanding the impact of these types of printers in the manufacturing environment;
- Development of re-use strategies for materials; and
- Development of process diagnostic and process control algorithms.

Outcomes

- Advanced new AM technology platforms in high-end metal AM and low-cost locally developed polymer-based systems to TRL 8 and 9 by 2020;
- New metal alloys with improved compatibility with AM;
- South African developed polymer consumable for AM;
- New technology packages that will support optimised usage of materials; and
- New technologies for process monitoring and control for AM production applications.

C1.2.4 Small, medium and macro enterprises development and support

The South African economy grew by 1.5% in 2015 and is predicted to slow down even further in 2016[25]. Unfortunately, a low economic growth rate is not adequate to provide the required number of jobs for the South African economy. This is clear from the high current unemployment rate of 24.9% (2016), which is even higher in the 15 to 25 year-old age group category. New manufacturing activity is key to job creation, including establishing new SMMEs. AM lends itself to SMME creation by providing innovative processes and techniques that can unlock product innovation, new product lines, faster production and (in principle) cheaper manufacturing than conventional manufacturing technologies.

Based on the feedback from the stakeholder workshops and other interactions with local industry, the following areas should be addressed as priorities for implementation of support programmes to enable adoption of AM by SMMEs:

- Production of prosthetics by use of AM technology;
- Production of crowns and bridges for dental industry;
- Production of customised hearing aids;
- Manufacture of jewellery; and
- Use of AM in the creative arts industries.


3D printing used in the fashion industry
(Source: Michaela Janse van Vuuren, Nomili)

Vision

The vision of this focus area is the adoption of AM technologies established within the SMME sector, having enabled them to be more competitive through realising the benefits offered by this technology over traditional manufacturing.

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[25] *http://www.statssa.gov.za*

Drivers[26]

- Innovation, economic development and employment creation through creation of smart industries;
- Increased geometric freedom;
- Flexible and reconfigurable manufacturing cells;
- Economic low volume production;
- Product customisation;
- Improvised environmental sustainability;
- New supply chains and retail models;
- Increased part functionality; and
- Futuristic drivers:
  - Multi-functional 3D printing;
  - Bio-packaging and bio-printing;
  - Organic supply chains;
  - Down-scaling of industrial technology;
  - Improvement of technology capabilities; and
  - Technology convergence.

Reversed engineered saddle
(Source: Rapid3D and Franco C Saddlery)

Objectives

This focus area seeks to unlock the potential of AM for improving competitiveness of manufacturing SMMEs. Broad objectives include the following:

- Raising awareness of AM technology and promoting technology know-how in the manufacturing SMME sector;
- Raising awareness of and providing access to existing SMME support programmes concerned with competitiveness improvement, skills development, new equipment acquisition, etc.;
- Providing support for incubating new SMMEs in sectors such as arts and crafts, jewellery, dental implants and hearing aid manufacture. The jewellery industry is of specific importance due to the abundance of local resources supporting this industry segment;
- Facilitating linkages between established R&D and industry players in AM, and interested SMMEs;
- Assisting SMMEs to identify and pursue new manufacturing opportunities; and
- Establishing technology demonstration and evaluation centres with the aim to support industry in decision-making regarding the manufacturing technology and manufacturing strategy, as well as supporting the incubation of service bureaus to support small volume production.

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[26] *With credit to Econolyst*

Outcomes

- Larger adoption of AM in South Africa in the established SMME sector; and
- Establishment of new AM producing companies (print bureaus).

C1.3 Enabling capability development

To ensure that AM becomes commercially viable in the South African market, it is not sufficient to only develop the manufacturing technology itself. It should be recognised that, as with any other technology, a number of other competencies are required to enable the successful implementation of AM. It is imperative that these capabilities are developed to ensure a strong competence and technology base in South Africa.

The core enabling capabilities required for the AM industry have been identified as:

- Design and design optimisation;
- Pre-processing (data);
- Process monitoring and control;
- Post-processing;
- Testing and analysis;
- Dimensional verification and reverse engineering; and
- Simulation and modelling.

C1.3.1 Design and design optimisation

For any manufacturing technology, the design of a part needs to adhere to certain design rules to ensure manufacturability and integrity of the part. Injection moulding, for example, requires draft angles, minimum wall thickness, corner radii, etc. The invention of injection moulding (and its associated design rules) consequently changed the way that parts are designed and had a large influence on modern-day aesthetics. However, the adoption of new design methodologies is not trivial as this requires identification of new design rules, training of designers, CAD software updates, new simulation tools, etc.

The layer-wise production method used by AM technologies is unique and ensures large design freedom in the AM process. The ‘freedom of design’ offered by AM is one of the main advantages of the technology as this allows for increased part complexity, parts count reduction, weight reduction, etc. When applied correctly, this can ensure significant improvements in part functionality and cost, especially in low-volume high-value part production.

To ensure that AM technology in South Africa is utilised to its full extent, it is essential that a design capability is established. The following are topics that should be addressed:

- Development of process-specific design rules;
- Development of syllabi for AM design;
- Training of a competent design force for AM; and
- Establishment of software capabilities for AM design and design optimisation.

Airbus door hinge design optimised for AM (Source: Airbus Group)

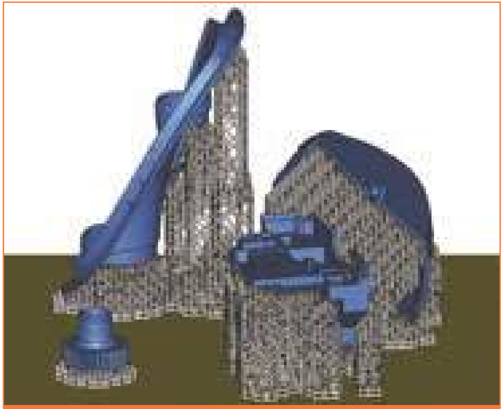
C1.3.2 Pre-processing (data)

A major advantage of AM is that it allows for the production of components, directly from CAD data, without the need for tooling or programming. However, the handling and preparation of the CAD data does require a number of capabilities that need to be established. This does not only include software tools, but also process know-how as well as trained operators with specific competencies in the field of AM.

Specific capabilities that need to be addressed include:

- Build strategy planning;
- Processing parameters;
- CAD preparation;
- Support structure generation; and
- CAD file configuration and management.

Build nesting software
(Source: CRPM, CUT, Materialise)



Support structures generation
(Source: CRPM, CUT, Materialise)

C1.3.3 Process monitoring and control

A concern regarding AM is the issue of quality control with respect to the part being produced. In powder bed fusion and direct energy deposition technology the raw material from which the part is manufactured is melted or consolidated 'on-the-fly' and the potential exists that defects may occur within parts if the manufacturing process is not well controlled.

One solution to this challenge is that various portions of the manufacturing process are continuously monitored and that this information can be used, either to verify that the process is within acceptable limits, or to provide feedback to the system to allow active control of the system. AM is, in principle, well adapted for this approach since it is theoretically possible to verify each layer, or even each 'pixel', of the part as the part is being produced.

There are various difficulties in implementing such monitoring and control systems because very high scan speeds, small spot sizes, high cooling rates, etc. imply that conventional measurement systems are inadequate for these applications. Limitations in adequate data handling technologies further complicate process monitoring and control to be implemented efficiently. Internationally, research in this field is prioritised; especially in the field of metal AM as these systems largely address the needs of the aerospace and medical fields which require high confidence in the quality of the final product.

C1.3.4 Post-processing

Post-processing of AM parts has been identified as one of the main enabling technologies required in South Africa, especially in the field of metal AM (MAM). Post-processing for AM can be categorised in two main categories, i.e. thermal processing and surface finishing. These technologies are often capital-intensive and although some of these capabilities exist in South Africa, some of them are underdeveloped and others still need to be established.

The manufacturing process for metal AM parts dictates that parts are manufactured with a very specific microstructure. Some form of thermal processing is often required to ensure compliance with final part specifications. Examples of thermal processes for AM parts include stress relieving, annealing and hot isostatic pressing (HIP).

Due to the layer-wise manufacturing process, the surface finish of AM-produced parts is of lower quality compared to what can be achieved with other manufacturing processes. Certain parts therefore often require additional surface finishing steps to ensure that parts are within specification. However, the high complexity of AM parts increases the difficulty for surface finishing. A number of methods are being developed to address some of these problems. Surface finishing includes processes such as machining, peening and polishing.

C1.3.5 Testing and analysis

To allow access to the international market for production of AM parts, it is essential to have access to certified testing equipment and laboratories.

Testing requirements are not only for verification of the integrity of the final part, but are also required for analysis of the raw material (feedstock). This includes facilities that allow for testing of metals, polymers ceramics, resins, etc. One of the most critical requirements is for testing of powders. All the metal AM processes currently operated or being developed in South Africa are powder processes and the numerous properties of powders have a large impact on the final product. Figure 19 indicates typical powder properties that affect the product.

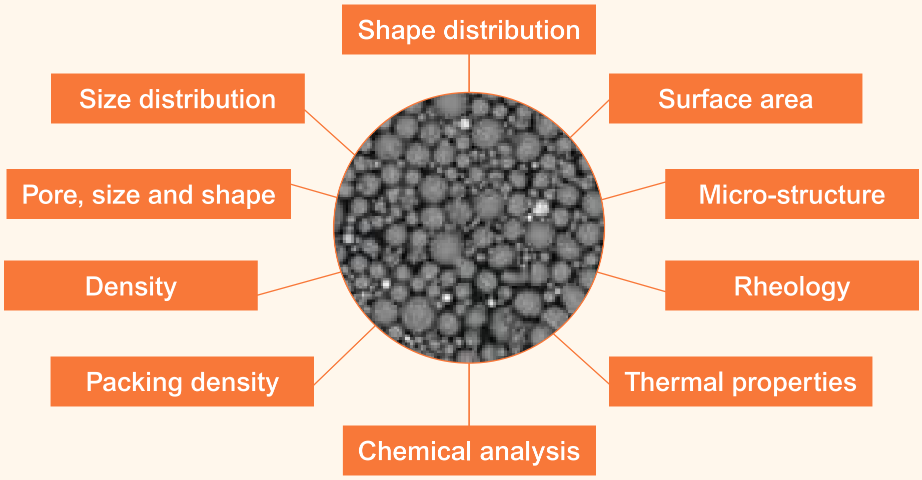


FIGURE 19: Powder properties that affect AM products
(Source: CSIR Materials Science and Manufacturing)

Some form of final product testing (destructive and non-destructive) is also a requirement on most high-end AM applications. This is not only required to test the properties of the final part, but also to develop AM processes that will meet the required specifications. Certain testing facilities are available in South Africa, but the main concerns that need to be addressed are capacity constraints and certification requirements.

C1.3.6 Dimensional verification and reverse engineering

The advent of AM (and its associated design freedom) has triggered a range of developments internationally in the field of reverse engineering. ‘Dimensional verification and reverse engineering’ covers a very wide range of equipment that is used in various applications. Systems range from highly-accurate coordinate measuring machine (CMM) facilities, to coherence tomography (CT) scanning equipment, to applications that turn cellular phones into 3D scanning devices. The applications for these systems are numerous and only a few examples are listed:

- Verification of dimensional accuracy on highly complex parts;
- Design of customised medical implants based on CT scan data;
- 3D scanning of faces for production of external prostheses or custom figurines; and
- Reverse engineering of legacy tools and parts.

Reverse engineering for facial prosthesis design (Source: CRPM, CUT)

One aspect that is often overlooked is the software requirement to ensure that the results obtained from the above equipment are usable for the specific application. Another aspect that requires attention is trained personnel with the required competencies.

C1.3.7 Simulation and modelling

To ensure the development of a vibrant AM industry in South Africa, it is essential that a very good basic understanding of AM processes is established. One of the tools to allow for this is the capability to model the manufacturing process and to simulate results based on specific input parameters. South Africa has extensive modelling capabilities, but specific modelling capabilities in the field of AM are, to a large extent, lacking.

As the material for the final product in AM is produced 'on-the-fly', the process parameters for any specific process or material can have a large effect on features such as microstructural evolution, residual stresses, dimensional tolerances, etc. By simulating selected areas of the AM processes, such as the laser-powder interaction area (weld pool), the thermal gradients in the process, etc., a very good understanding of the process can be created to ensure efficient process optimisation, highly controlled process parameters and faster time-to-market.

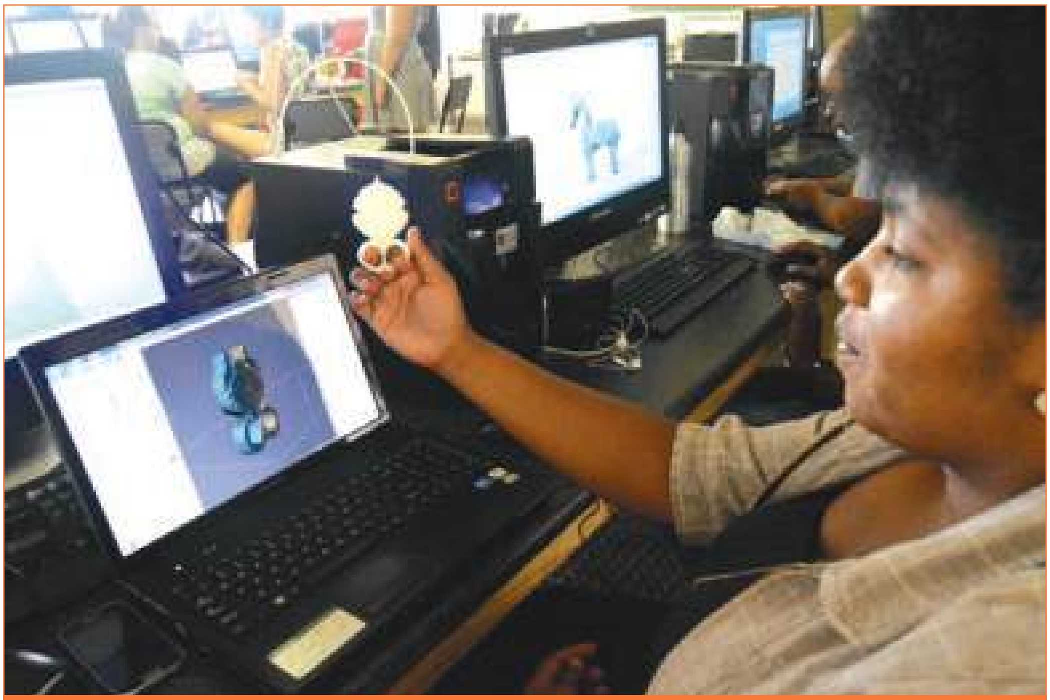
C1.4 Education, training and awareness creation

Apart from the AM technology-based enablers referred to in the previous section, there are other broadly supportive enablers that need to be in place to support the establishment of a sustainable AM industry in South Africa. In particular, the industry needs to be supported by changes in the secondary and tertiary education sectors, an effective promotion and awareness strategy and plans, and the establishment of a value-adding industry database. The manner in which the implementation of the strategy is managed and implemented is also of critical importance.

C1.4.1 Enabling education system

AM is a relatively new technology and as such there is very little established educational or training programmes tailored towards the needs of the AM community in South Africa. As the technology grows in South Africa, the need for educated personnel in this field is becoming more apparent. During the stakeholder workshops, education was highlighted as one of the main priorities to ensure successful adoption of the technology in South Africa. The following were identified during the workshops as imperatives to ensure AM education at various levels, from schools to Higher Educational Institutions to industry:

- Develop a short, medium and long-term educational framework for AM;
- Ensure school-level interventions to facilitate exposure to the technology;
- Provide widespread access to the technology at school level, e.g. through computer labs and CAD courses;
- Establish a national AM curriculum for all design and engineering schools at Higher Educational Institutions;
- Establish a dedicated bursary programme for pre- and post-graduate studies in the field of AM;
- Secure National Research Foundation and Department of Science and Technology Research Chairs for AM; and
- Establish national AM centres at strategic locations.



I2P Lab (Source: VUT)

The nature of AM is such that educated individuals are required from a large number of fields to support the multitude of application areas, the technologies employed in AM, as well as the materials science requirements of the processes. It is suggested that AM is introduced to at least the following educational areas:

- Engineers and technicians
  - Mechanics;
  - Metallurgy;
  - Materials science;
  - Optics;
  - Biomedical;
- Designers
  - Mechanical;
  - Industrial;
  - Creative arts;
- Medical field
  - Orthopaedic surgeons;
  - Dental surgeons;
  - Prosthodontists;
  - Dental technicians;
  - Orthoptists and prosthetists;
- Other fields include
  - Materials science;
  - Reverse engineering; and
  - Operator training.

In terms of education the following objectives have been identified:

- Identify core competencies needed in the field of AM;
- Create dedicated AM programmes for development from secondary school to Higher Educational Institution levels;
- Development of common terminology and a core curriculum for focused educational and training programmes;
- Improve education and training programmes and increase student career eligibility;
- Develop specialised tracks in AM for R&D, design of systems, process development, materials development, etc.;
- Set up specialised research clusters to define strengths of regions; and
- Enable an international exchange with universities and other research centres.


I2P laboratory (Source: VUT)

One of the very successful educational initiatives in South Africa is the 'Idea to Product' laboratories. South Africa in general, but more specifically poverty-stricken areas such as southern Gauteng, is challenged with low levels of skills development, underpinned by insufficient job opportunities. As part of an innovation and job creation strategy-driven solution, the Vaal University of Technology introduced an Idea 2 Product Lab™ (I2P Lab™) where, as a strategic intervention, individuals from the region can be provided with appropriate skills development, infrastructure for entrepreneurs to develop new products that can be tested and modified in the market place according to customer needs and increased adoption and transfer of technology and R&D into new tools for entrepreneurs. The project (through its dedicated and virtually linked laboratory facilities) also provides infrastructure to produce small batches of niche products.

C1.4.2 Promotion and awareness

AM is still an emerging technology and, as such, is not well understood. During the last number of years, the technology has fortunately received unprecedented media coverage which created some level of awareness of the technology. Despite the media hype, AM is still largely unknown and a number of perceptions and misconceptions have been created in industry with regard to the technology. It has been recognised that a strong emphasis should be placed on an awareness strategy that will not only promote, but also serve to educate the manufacturing industry on the advantages of using the technology for prototyping as well as final part production. Further, it is recommended that a strong brand should be developed and actively promoted for the South African AM initiative.

Effective engagement with the various stakeholders to ensure the most beneficial direction for the future of AM is critical. The requirements of developing a unified education strategy along with establishing the appropriate partnerships with other key institutions and organisations are vast and complicated.

The development of a communication strategy for AM in South Africa is imperative. This strategy should be two-fold in that a general 'promotion and awareness strategy' is required, as well as a specific 'science communication and engagement strategy'. These should employ various communication vehicles and media, e.g. workshops, a website, print media, social media, etc. Demonstration of the capabilities in AM through visible and practical applications of the technology in the social and retail environments can assist in stimulating acceptance of the technology. The following activities should receive attention to ensure that the South African industry and marketplace become aware of the potential benefits that AM can deliver to local industry:

- AM-related competitions;
- Industry awareness and training events;
- Public awareness and training programmes;
- Regular feedback and dialogue sessions with stakeholders (public and private sector);
- Establishment of a South African 3D printing forum;
- Share and showcase industry success stories;
- Flagship projects to demonstrate AM benefits;
- Technology demonstration and development centres available to the public;
- A database of AM-related technologies and services in the South African market;
- Engagement with science centres and journals; and
- Engagement with industry associations.

To accomplish this, an integrated communication strategy will need to be developed to address both the type of content and the distribution channels to ensure awareness and public education. Learning from international experiences and feedback from local industry, content could include:

- Demonstration of capabilities;
- Available infrastructure;
- Links with other national or international AM-related activities;
- Sector-specific case studies and success stories;
- 'Getting to grips' with AM terminology and applications; and
- Role models.

Appropriate communication channels could be:
- Editorial videos;
- Blogs;
- Articles;
- White Papers;
- Websites;
- Social media e.g. Twitter, Facebook;
- General public media, such as television and newspapers;
- Exhibitions;
- Promotions;
- Science cafés;
- Popular technical media; and
- Site visits and tours.

C1.4.3 Additive manufacturing database

In addition to developing awareness, it is important to create a centralised database with information that is readily available to entrepreneurs. The approach should include:

- A database of users and service providers;
- Provide capabilities of machines and properties of materials in the database;
- Create a database of capabilities, materials and markets;
- Create a 'go-to' guide matching industry applications with AM processes to use; and
- Provide adequate resources to ensure the database is accurate and maintained.

As an initial step, a web-based portal (possibly on the RAPDASA website) should be created for AM where stakeholders can access the type of content listed above and information on AM and where the media can access general information about AM. The web-based portal should be used to manage a database that will give the South African AM community access to, or information about:

- Case studies, reports, foresight studies, white papers on areas of common interest;
- Capabilities of local institutions;
- Local infrastructure;
- Local and international funding opportunities;
- Links with other national or international AM related activities;
- Contact information; and
- Analysis of areas of common interest.

By utilising the interactions with the AM community through the web-based portal, information can be accessed that can be used to submit proposals to national and international support programmes for support of AM. By sharing experiences, the needs of AM in the broader community can be identified and mutual benefit will be derived from the collaboration between the community and government.

C2 Implementation of the SA Additive Manufacturing Strategy

It is proposed that an AM Steering Committee is established to primarily provide the strategic leadership with respect to the further refinement of the SA AM Strategy and to oversee the implementation of the programmes in support of the strategy.

The Steering Committee will have representation from the various key industry segments such as aerospace, medical implants and devices, tooling, automotive, SMME sector, as well as representatives from government departments. Technology leaders in AM from research institutions active within the National System of Innovation will also be invited. Appointment to the Steering Committee could be done by the Department of Science and Technology or RAPDASA and could be renewed every two years.

The Steering Committee will have the responsibility to:

- Review and endorse the strategy, as well as the programmes and projects proposed in support of the strategy;
- Identify possible sources of funding for programmes and projects supported for the implementation of the strategy;
- Engage with stakeholders from other government departments, private sector and higher education institutions to support the implementation of the strategy;
- Ensure that new mechanisms and initiatives are established and existing initiatives are supported for creating and growing general awareness of AM, as well as acceptance and implementation of the technology in the industry, as defined and proposed in the strategy;
- Establish a review framework that will be used to monitor the execution of programmes aligned with the strategy;
- Advise on strong guidelines to ensure adherence to good governance principles;
- Recommend on the implementation and execution of the programmes in support of the strategy; and
- Ensure that RAPDASA as industry association will also play a key role in the review of the AM Strategy, as well as form part of the Steering Committee to oversee the implementation programmes flowing from the strategy.

With respect to the management of the implementation programmes of the strategy, it is proposed that a portfolio management approach be established. The CSIR as implementation partner for the Department of Science and Technology is well positioned to support the implementation programs funded by the DST. The responsibilities of the CSIR with respect to implementation can include:

- Ensuring that funding is applied in support of the national initiatives as defined in the approved SA AM Strategy;
- Being responsible for contracting with the various institutions, as well as programme coordination;
- Ensuring that regular reviews of the progress in approved programmes and projects are done and that funders and stakeholders receive reports and feedback; and
- Participation in the R&D programmes.

Acknowledgements

In the development of the South African Additive Manufacturing Strategy, the core team interacted with a wide range of stakeholders to gather data, discuss trends, share concepts and refine ideas. This included individuals within the formal academic sector, government, science councils, machine resellers, industrial users of the technology and small enterprises and entrepreneurs. Many individuals sacrificed time and energy to contribute to this process. Without this valuable input this strategy would not have been accepted by the larger AM community.

The core team wishes to express its gratitude to all contributors who made this process possible. The next step to define, resource and implement programmes to address the research areas identified through the roadmapping process is of critical importance to ensure that South Africa becomes a player and leader in niche areas of AM.

Appendix A: Background and methodology

A.1 Background to the strategy

The Department of Science and Technology commissioned the development of an Additive Manufacturing Technology Roadmap for South Africa in October 2013. The adoption of AM in South Africa started in the early 1990s through a consortium which included the Council for Scientific and Industrial Research (CSIR) and a number of Higher Educational Institutions. This resulted in the procurement and placement of the first rapid prototyping system at the CSIR. Since then interest has grown in the technology, with an exponential growth in the number of systems installed in South Africa over the past four to five years. An important driver of the AM technology in South Africa has been the Rapid Product Development Association of South Africa (RAPDASA). RAPDASA was born from the realisation by a number of individuals from academia, the CSIR and private companies, of the very positive impact this disruptive technology could have on the South African manufacturing industry. Since its inception in 2000, RAPDASA's primary objective has been to create awareness of the importance of AM for maintaining international relevance and competitiveness for South African industry.

Given the successful assimilation of the AM technology by the South African industry and the potential of this technology to provide companies with strong competitive advantages, the need to develop an AM technology roadmap for the country has been recognised by RAPDASA. In its 2012 Annual General Meeting a resolution was adopted to pursue the development of such a roadmap. The RAPDASA Management Committee via the CSIR subsequently submitted a proposal to the Department of Science and Technology to fund the development of an AM Technology Roadmap.

The brief from the Department of Science and Technology was to develop an AM Technology Roadmap that identifies prioritised future addressable market opportunities and associated products, and the resource requirements to access these opportunities. The primary purpose of the Roadmap is to develop an implementation framework to guide public and private sector investment in AM research, development and innovation (RDI) in South Africa for the period 2014-2023. Included in the implementation framework will be a set of prioritised and detailed actionable plans (in two to four niche areas) to take advantage of high-priority opportunities to contribute towards South Africa's socio-economic imperatives. A secondary purpose is to devise an AM science communication strategy to generate interest in science, technology, engineering, mathematics and innovation (STEMI) among industry, entrepreneurs and the public. Within this strategy there should be a specific intention of educating and creating awareness of AM among manufacturers, designers and entrepreneurs.

The strategy that was developed as the outcome of the roadmapping process is believed to be an over-arching strategy on how to move AM forward in South Africa. In the review of the process that was followed to develop this document, as well as the review of the document itself, consensus was reached between the Department of Science and Technology and the team responsible for the development of this document to refer to this as the **SA Additive Manufacturing Strategy** document instead of the SA Additive Manufacturing Technology Roadmap. It is hoped by the authors and the DST that referring to this document as the South African Additive Manufacturing Strategy will allow other government line departments, as well as public and private sector stakeholders to adopt the strategy as a national strategy for Additive Manufacturing in South Africa.

A.2 Methodology

This SA AM Strategy was developed through a combination of desktop research, international market research, facilitated stakeholder workshops, a survey of local capabilities through meetings and questionnaires, and deliberations within the project core team comprising local experts in AM and technology roadmapping approaches.

The desktop research was conducted primarily by project core team members with their broad knowledge of AM and ready access to information. The desktop research included studying AM roadmaps developed elsewhere in the world, as well as gathering information about recent AM technology developments and applications. Terry Wohlers, a leading international expert in AM, was contracted to provide information on international trends and drivers and to contextualise the South African AM landscape against these global developments.

Facilitated workshops were held in Cape Town, Durban and Johannesburg in November 2013 to solicit the views of a diverse set of stakeholders including industry, government, higher education institutions, service providers and R&D institutes. The workshop inputs were summarised and prioritised to provide useable input to the development of the SA AM Strategy. Excluding the core team members, a total of 105 people representing industry, government, tertiary education institutions, research organisations and service providers participated in the stakeholder workshops. The full list of attendees is attached as Appendix B.

Representation across the various sectors is summarised below.

Sector participation in the SA AM Strategy workshops

Sector	No. of participants
Industry	53
Government	14
Higher education institutions	25
Research institutes	4
Service providers	9

Local AM capability was surveyed through a combination of personal interviews, visits to AM facilities, a mail-based questionnaire and the core team's personal knowledge of the industry.

The project core team was ultimately responsible for selecting the focus areas and designing the proposed interventions, after taking into account all the information and views gathered. The research areas and interventions were tested with the Department of Science and Technology, **the dti** and selected experts in the AM community. These were refined in an iterative manner as required, before the strategy was finalised.

Appendix B: Workshop attendees

Apart from the attendees listed at each of the workshops, the core team members, representatives from the Department of Science and Technology and a facilitator, Peter Thomas, attended all the workshop events.

Participating institutions in the SA AM Strategy development workshops

Name	Company
Afzal Chothia	WEIR Minerals Africa
Alan Alborough	CCDI
Andries Uys	Aerosud
Anita Stanbury	Dept Economic Developt & Tourism – W.Cape Govt
Awie Viljoen	Altech
Barend Vermaak	Paramount Advanced Technologies
Bernard Garcia	Turbomeca Africa
Bob Bond	Tshwane University of Technology
Bonisani Nzama	Department of Science and Technology
Brent Cadle	XANITA
Cedrik Kotzermacher	Fischer
Chantel Botha	Denel Dynamics
Charmaine Johnston	CSIR
Chris Neveling	XANITA
Claude Orgill	Economic Development
Clive Oliphan	NMISA
Cobus Schutte	Hatch
Danie Loots	Denel Aerostructures
Danie Prince	Adcock
Danielle Kruger	Frost & Sullivan
David Mdungazi	Dept. Economic Developt, Environment & Tourism
Deon Lategan	Denel Spaceteq
Dimitri Dimitrov	Stellenbosch University
Dirk Hoffman	Conro Precision
Dirk Kotze	RDM Boskop
Ellen Hüster	Technology Innovation Agency
Erwin von Maltitz	3-D Printing Systems SA (Pty) Ltd
Eugene Erfort	Cape Peninsula University of Technology
Farouk Varachia	University of Johannesburg
Francois v Eeden	Transnet Eng

Name	Company
Gavin Leggott	Rapid 3D Gauteng Sales Partner
George Oliver	Vision Data Systems
Gerhard Vorster	Customed
Hano Steyn	Denel Spaceteq
Helen van Mellido	3D printing Systems
Henna du Plessis	Transnet
Hennie Britz	Pretoria Metal Pressings (PMP)
I. Engelbrecht	Innoworxx
Irfaan A Khota	Industrial Development Corporation
Ivan Shamley	Rapid 3D
Ivan Venter	Architect
Jacques Kleynhans	Demaplastech
Jaime Chan	Industrial Development Corporation
James Beattie	XANITA
James Fungai Maposa	Frost & Sullivan
Jan Jooste	Vaal University of Technology
Javier de Corral	CDTI Spain Innovation Agent
Johann Nel	NECSA
Johann Strauss	Paramount Advanced Technologies
Jon Kerr	GKN Sinter Metals – Cape Town
Khumbulani Mpofu	Tshwane University of Technology
Leslie Becker	Vaal University of Technology
M.E. Letsoalo	Limpopo Fablab
Makinde Olasumbo	Tshwane University of Technology
Marco Kotzenmacher	Fischer
Marius Grobler	Paramount Advanced Technologies
Mark Zuckerman	Zuckerman Sachs Architects
Marthinus van Wyk	Dept Economic Developt & Tourism – W.Cape Govt
Mendon Dewa	Durban University of Technology
Michael McElwee	XANITA
Michael Sam	Cape Peninsula University of Technology
Michael Vermooten	PMP Denel
Michiel Morapeli	University of Johannesburg
Mmamose Seloane	Technology Innovation Agency
Moses Mogotlane	Technology Innovation Agency
Motsama Mollo	Ford
Mr M.Nemadodzi	Limpopo Tooling Initiative
Nnzeni Netshitomboni	Industrial Development Corporation

Name	Company
Nomulat Tsolb	**the dti**
Norman Gwangusut	Tshwane University of Technology
Nyaka Crisantia	Tshwane University of Technology
Olabanji Olayinka M	Tshwane University of Technology
Oscar Philander	Cape Peninsula University of Technology
OT Adenuga	Tshwane University of Technology
Paul Cronje	Denel Dynamics
Paul Robbertse	Denel Spaceteq
Pauline	Rapid 3D
Peter Venter	Arcelor Mittal South Africa
Philip Hugo	RPD Stellenbosch Univ
Pieter Cilliers	CCDI
Pieter Erasmus	Mechanical engineering graduate
Quentin Harley	Reprapmorgan.com
Rasheedat M. Mahamood	University of Johannesburg
Riaan Strauss	Pro-3D-Manufacturing
Richard Schulz	Adept Air Motive
Robert Bloom	Creo Consulting
Robert Honiball	Customed
Robert König	Agents of the 3D revolution
Ron MacLarty	Afrimold
Ryan Hamilton	Durban University of Technology, Technology Station
Ryan Raath	CSIR
Samuel Seeff	Seeff
Sanjay Dhani	Denel Dynamics
Sarah Wild	Science Editor, Mail and Guardian
Shaun Roach	Welding Alloys SA
Sinothi (SD) Maphumulo	Sasol
Takalani Madima	**the dti**
Takalani Madzivhandila	University of Johannesburg
Terri Berntein	Afrimold
Uttam Pancha	Durban University of Technology
Victoria Cain	Cape Peninsula University of Technology
Willem Esterhuyse	MeerKAT
Willie van Biljon	DCD Mobility
Wynand Louw	NMISA
Wynand Viljoen	Central University of Technology

Appendix C: List of 3D printing bureaus

Company	Website	Location
3D Warehouse	www.3dwarehouse.co.za	Durban, Kwazulu-Natal
3D Forms	www.3dforms.co.za	Johannesburg, Gauteng
3D Pro	www.3dpro.co.za	Durban, KwaZulu-Natal
3D Solids Additive Manufacturing Technology	www.3dsolids.co.za	Pretoria, Gauteng
BlowIn Graphics	www.blow-in.com	Rand Airport, Gauteng
CAD House Production 3D Printing	www.cad-house.co.za	Midrand, Gauteng
Custom3D Rapid Prototyping	www.custom3d.co.za	Somerset West, Western Cape
Demaplastech	www.demaplastech.co.za	Northriding, Gauteng
DMS RAPID	www.dmsrapid.com	Henley on Klip, Gauteng
Innovative 3D	www.innovative3d.co.za	Johannesburg, Gauteng
Jewelcam	www.jewelcam.co.za	Cape Town, South Africa
KVR Design and Prototyping	www.kvrdesign.com	Cape Town, Western Cape
Protogrow	www.protogrow.co.za	Pretoria, Gauteng
Rabbit	www.therealrabbit.com	Cape Town, Western Cape
Rapid Productions Systems (RPS)	www.therealrabbit.com	Centurion, Gauteng
SolidEdge Technologies	www.setech.co.za	Brakpan, Gauteng

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