

THE IMPACT OF ADDITIVE FABRICATION TECHNOLOGIES ON INSTITUTIONAL RESEARCH DEVELOPMENT AND THE SA PRODUCT DEVELOPMENT COMMUNITY-THE CRPM STORY

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ABSTRACT

The Centre for Rapid Prototyping and Manufacturing (CRPM) made a humble start in 1997 as a spin-off from a proposed research activity in 1995, at a stage when Technikons were still being seen as occupational training institutions rather than higher education institutions and as such, were not funded for research. Addressing an area of high importance to the South African industry, the research activity soon grew into a research unit, commercial centre/centre of excellence, technology transfer unit and innovation support centre. Above all, the research started to impact on product development practices to deliver improved products. The paper considers the development of the available technology platforms at the CUT'S CRPM to become a technology power-house on the African continent, and how it impacted on Institutional Research Development in South Africa.

Key words: Rapid Prototyping, Rapid Tooling, Rapid Manufacturing, Additive Manufacturing, Computer Aided Design, Computer Aided Manufacturing, Computer Numerical Control.

1. INTRODUCTION

Rapid Prototyping (RP) is the collective name for a set of technologies and processes used to manufacture models directly from a three-dimensional (3D) CAD model by building them as a series of layers. The processes include, amongst others, Stereolithography (SL), Laser Sintering (LS), Fused Deposition Modelling (FDM) and 3-Dimensional Printing (3DP). Other associated names are Additive Manufacturing, Solid Freeform Fabrication (SFF) and Layered Manufacturing. RP has gained diversity, complexity, sophistication and popularity since its introduction in the late 1980's, and thus far have been used to support Rapid Product Development (RPD) - a manufacturing methodology that accelerates the development of new products, from the initial design stage to mass production. RPD involves new technologies such as Computer Aided Manufacturing and Design Technologies (3D CAD/CAM), RP and Rapid Tooling (RT), combined with new management philosophies, to address the reduction of development time in order to streamline the manufacturing process. RPD techniques not only allow companies to put new products into manufacturing faster, but also concurrently reduce associated development costs. Internationally, companies are finding these techniques to be extremely beneficial and it is adopted at an ever-increasing rate.

Starting from a position of lagging behind other industrialised countries, South Africa (and Higher Education Institutions wanting to research the emerging field of additive manufacturing) had a challenge to face. Limited numbers of RP machines were introduced into the country and put to work in a wide range of applications by both the CSIR and one private company. However, the development was not undertaken in a haphazard way and co-operation between HE, industry and government was aimed at an efficient use of the country's limited economic resources. In this collaborative way, the CUT (then-called Technikon Free State (TFS)) became involved with the CSIR through the author's research project. As limited technologies were available in South Africa, it posed both a challenge and opportunity for the CUT to develop a novel research niche area (RNA), which could lead to an activity in support of industry needs and in response to government priorities (addressing both the then Department of Arts Culture Science and Technology's (DACST) White Paper on Science and Technology, as well as the Committee of Technikon Principal's (CTP) research directive for Technikon's). It also meant that for the CUT it offered an area for research development that would not have to trail behind existing university research areas that have been under development for a number of decades. As this was entirely a new research field, it furthermore implied that any other institution opting to investigate the same research questions, would face the same hurdles to make development progress, leaving the CUT in a leading position as an early South African academic adopter of these technologies. It also offered the opportunity for the CUT to accelerate research development and to become an acknowledged activity in a fairly short time.

2. INITIAL INTRODUCTION OF RP SYSTEMS AND APPLICATIONS TO SOUTH AFRICA

The first RP system was introduced into South Africa in 1994. It was a 3D Systems SLA 250 machine purchased by the 3D Systems agent in South Africa, and at a certain stage operated under a private company called Rapid Design Technologies (RDT). This was followed by two FDM 1500 machines, which were later upgraded to 1650s, owned by the Council for Scientific and Industrial Research (CSIR). The CUT (called TFS at the time) purchased a Sanders ModelMaker II and an SLA250 in 1996. The CSIR installed an SLA 500 in the same year and two years later, the TFS purchased a used DTM Sinterstation 2000. Hence, by the end of 1998 there were seven RP machines in the country (Wohlers, 1999). It is important to note that only one of these was owned by a private company. This is indicative of the fact that RP was initially introduced into HE and other research institutions with the aim of assisting their co-operation with industry. In addition, the diverse and complementary nature of the machines installed allowed active collaboration, efficient planning and conducting of research programmes. Further steady growth took the overall number of machines in 2003 to 17 with only two in private companies (Wohlers, 2004). It was at this stage that RP implementation within South Africa began to follow a new direction. Although 35% of installed systems in 2003 were 3D printers, a significant 60% of new orders placed in that year were for this type of machine. This seemed to give (at least for South Africa) a very positive answer to the question posed by

Terry Wohlers, i.e. "will 2003 be the year for 3D printers?" (Wohlers, 2003). This trend towards 3D printers has continued to develop in South Africa and has led to a marked increase in the recent rate of growth of the RP machine base (see figure 1). This was at a time when RP growth in some parts of the world has slowed down or even stagnated (Campbell, 2005).

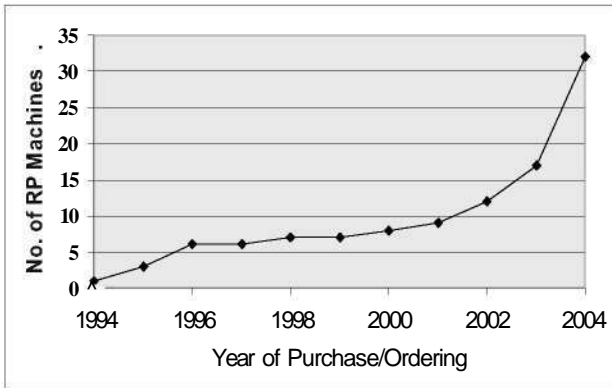


Figure 1: Growth of RP machine base in South Africa, 1994 to 2004

Although RP came relatively late to SA, much knowledge was already available (through international case studies, vendor's literature, etc.) on what it could be used for. This meant that South African HE institutions, and in particular the CUT, were quickly able to identify relevant application areas where they should become active. A wide range of application areas was sought out since the manufacturing industry base in SA was relatively small (although growing steadily). These included automotive components, anthropological studies, jewellery masters, medical visualisation, industrial design models, architectural models, low-volume tooling and rapid manufacturing of functional parts. A crucial aspect of this work was the raising of awareness of RP within SA through publishing case studies, exhibiting at trade shows, offering subsidised trials to companies, organising workshops, etc. The net result was that a great deal of experience in using RP was gained quickly and the potential economic developmental role of RP within SA was clearly defined (Campbell, 2005).

3. EFFECT ON RP DEVELOPMENT THROUGH RESEARCH AND GOVERNMENT INITIATIVES

Research has been undertaken in both South Africa's HE institutions and also at the CSIR which is a government-backed organisation that has responsibility for developing innovation in a wide range of areas. Most of the research has been applications-based, often in response to specific industrial needs. Typical examples have been reported by Vincent (2001), de Beer (2001) and Young (2003). This situation has arisen primarily from the manner in which machines have typically been funded, i.e. through government support where collaboration with industry has been a central aspect of the grant. A corollary

of this has been the high level of industrial participation in many of the research programmes. Sometimes the machines have been funded for a particular application but with a remit to look for wider application and an obligation to transfer into commercial operation. Therefore, research institutions have also become technology demonstration centres. As well as developing better ways to produce models and components, the impact of RP upon managerial aspects of the product development process has also been studied, e.g. product development innovation (Dimitrov, 2002) and support of concurrent engineering (De Beer, 2002).

RP implementation and research has proceeded with the firm support of central government. One reason for this is that the 1998 National Research and Technology Foresight Project's Manufacturing Report produced for the Department of Science and Technology (DST, 1998) showed that manufacturers wishing to compete internationally should focus on integrated product development, process and production system design to speed up production time. The report also listed RP and RT amongst the key technologies that would assist with this aim. This indicates that RP and related technologies have been firmly established within the SA government's strategy for industrial development for the past five years.

Government support for RP research has come both directly, through funding made available to purchase RP systems, but also through a series of initiatives where RP has been able to play a prominent role. For example, the National Product Development Centre (at the CSIR) was launched as the hub of a national network giving support to the manufacturing industry. Members of the network include the Automotive Industry Development Centre in Gauteng Province, the CRPM in Bloemfontein, the Global Competitive Centre and Stellenbosch Automotive Engineering (both in the Western Cape Province), the Centre for Engineering Research in Durban, the Automotive Components Technology Station in Port Elizabeth and the Centre for Design and Manufacturing at North West University in Potchefstroom. Many of these centres are also active in RP research and have been able to develop this aspect further within the network. The network promotes active collaboration between centres with different RP systems to the benefit South African product developers (Campbell, 2005).

The Technology and Human Resources for Industry Programme (THRIP) provides 50% funding for collaboration between industry and academia (the other 50% coming from the industrial partner). Several research institutions have made very effective use of this for industry-related RP research including the CUT, CSIR and University of Stellenbosch.

The Technology Stations Programme has been established under the auspices of the Tshumisano Trust (a name that means co-operation or partnership) to promote the transfer of technology from technical universities to small and medium-sized enterprises (Tshumisano, 2004). Each technology station has its own area of expertise with several of them covering topics relating to product development technologies, e.g. the station at the CUT

focuses on metals value adding and product development. Once again, RP has an important role to play in the technology transfer process.

Other government-led activities that are leading to further opportunities for RP research and development are the National Research and Development Strategy (DST, 2001), the Advanced Manufacturing Technology Strategy (AMTS) from the National Advisory Council on Innovation (NACI, 2003) and the South African Tooling Industry Support Initiative (Maruping, 2004).

4. CONTRIBUTION TO RP DEVELOPMENT BY RAPDASA AND ITS ANNUAL CONFERENCE

No discussion of RP in SA would be complete without reference to RAPDASA (the Rapid Product Development Association of South Africa). It was formed in 1999 to act as the representative organisation for those involved in the RP and wider RPD community within SA. It has members from both research organisations and industrial companies. The organising committee is composed in a manner that reflects this diversity. RAPDASA is involved in range of activities that are all aimed at encouraging the further development and usage of RPD technologies. Most important of these is the annual conference, the first of which was held in 2000. The conference offers a platform for researchers and practitioners to share their knowledge and experience with others. It has benefited from international participation from its outset and, hence, attendees can also discover what is happening in the RPD world outside SA. A further consequence of this international participation is that the conference has become an international information source for RP developments in SA. RAPDASA has close ties with GARPA (Global Alliance of RP Associations) and first hosted a GARPA international summit at the conference held in 2001. The role that RAPDASA has undertaken has contributed much to the progress of RP&M in SA. A particular strength is that its remit is not limited to RP and so the relationships with other RPD technologies and the product development process feature widely in its activities (Campbell, 2005).

5. CURRENT STATE OF RP TECHNOLOGY PLATFORMS IN SOUTH AFRICA

Following the initial introduction of RP Technologies, together with the support from focused government- and research programmes and RAPDASA, the growth shown in Figure 1 was maintained. In January 2007 the author, as part of his annual contribution to the Wohlers Annual State of the Rapid Prototyping and Tooling Industry Report, commented that "Continuous growth is experienced in the use of additive fabrication, CAD/CAM, and related technologies in South Africa. With wider industry acceptance of the technologies, the number of additive machines installed during 2006 continued the growth pattern set during preceding years. Designers that fully understand the competitive edge of using Rapid Manufacturing are continuously challenging the technology and it is expected that excellent results achieved, will significantly expand the future use of additive manufacturing technologies" Wohlers, 2007).

Led by the upward turn in technology acquisition reported in 2004 (represented in Figure 1) significant growth in the number of RP machines available in SA was again reported in 2005:

- 12 machines sold in 2004, cumulative number of 27 in SA;
- 27 machines sold in 2005, cumulative number of 54 in SA.

This very positive trend again continued its pattern, with 36 more machines sold in 2006, adding up to 90 machines available in SA.

A significant proportion of these machines (both sold and as a percentage of the cumulative total) still falls within the 3D Printing category, as 92% (compared to 77,8% in 2005) of available machines still are 3D printers, and the same category represents 33 of the 36 machines sold during the period of reporting. (True to the predicted growth of 3D printers by Wohlers Associates, as during 2004, 62% of the total number of machines in SA fell in this category, with a reported growth of 50% from 2003 to 2004).

Figure 2 represents the growth in additive manufacturing technologies in SA whilst Figure 3 shows the number of original equipment manufacturers (OEMs) present in SA:

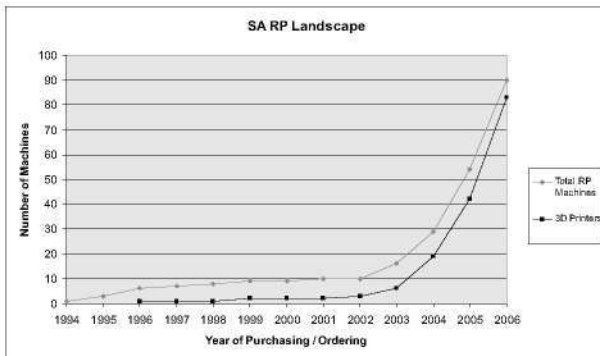


Figure 2: SA RP Landscape - January 2007

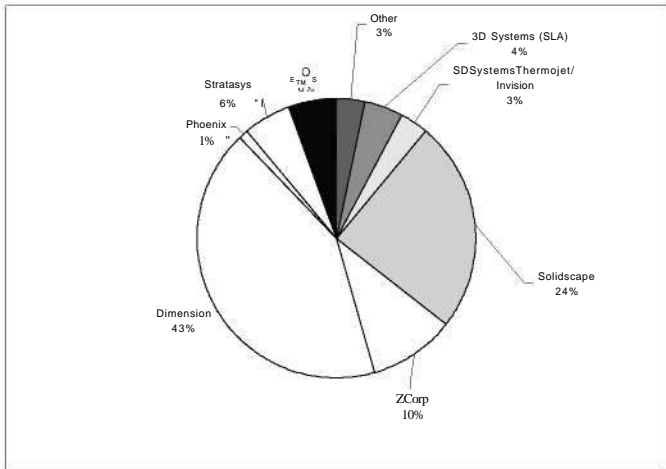


Figure 3: Representation of technologies and OEMs in SA

Industry ownership of RP machines is outgrowing academic ownership by far. The continuous lowering of 3D Printer prices definitely contributes to a wide variety of industries becoming involved in additive manufacturing, and is probably a product of South Africa's National R&D Strategy which attempts to draw SMMEs into the country's Innovation Network, and clearly illustrates that technology transfer from universities to industry through government support programmes is paying off.

6. CRPM'S ROLE WITHIN THE SA LANDSCAPE.

As an early adopter in SA, the CRPM development (although a success story), was not the mere acquisition and implementation of technologies. Initially, the total SA research system of funding through peer evaluation was the biggest hurdle, as very few persons were informed about these technologies, and hence, did not understand its application in industry in general - let alone the SA industry, and in particular having the Free State as home-base. Furthermore, international OEM support for single installations was a difficult equation to solve. It soon became evident that isolated installations would not be a sustainable operation for the CUT, which posed a further challenge, namely to fund further acquisition. Strategic support from the CUT and some private partners however, made the first two acquisitions possible. Backed by initial support from the NRF and later THRIP started to change the landscape and more and more industries were getting involved - either through single projects, or through involvement in more strategic projects that started to involve the acquisition of new/strategic platforms and developments, which laid the foundation for a series of private/public partnerships (PPP). CRPM became a prime example of how a HEI could position itself through direct triple helix models, and a specific process chain started to develop. Initially, there was only a research focus with limited

participation. To be sustainable, a "commercial centre" was developed to support both research and industry applications. In turn, this initiative was recognised by the DST and a pilot Technology Transfer Unit (Technology Station) developed on the German Steinbeiss model was funded by DST to accelerate the transfer and diffusion of technology to industry. CRPM became a support structure for both research and technology transfer, and further investments through a combination of own funds (surplus funds), institutional funding, industry and government grants started to follow on almost an annual base. In just more than a decade, CRPM became a national research centre, in parallel with being a technology demonstration, transfer and diffusion centre. Lastly, CRPM became an internationally recognised centre of excellence that boasts the following additive manufacturing technology platforms:

- Solidscape 3D Printer (initial machine bought in 1995/6);
- SLA 250 (bought in 1996)
- DTM Sinterstation 2000 (bought in 1998)
- EOS P380 Laser Sintering (LS) (bought in 2003)
- EOS S700 LS (bought in 2004)
- Dimension 3D printer (bought in 2004)
- SLA Viper si2 (bought in 2005)
- EOS M250X Direct Metal Laser Sintering (DMLS) (bought in 2006)
- EOS P385 (bought in 2006)
- EOS M270 Direct Ti Laser Sintering (DTLS) (bought in 2007)
- SLA 500 (Donated by the CSIR in 2007)

In addition to running the technology platform listed above in a research and technology transfer and diffusion mode, the following ancillary support systems and technology platforms have been developed or acquired:

- Computer Aided Design (CAD), Computer Aided Engineering (CAE) and Computer Aided Manufacturing (CAM) in parallel with reverse engineering and quality control / inspection software;
- Computer Numerical Control (CNC) machining (conventional and high speed machining);
- Reverse Engineering (RE) through touch probe scanning, laser scanning and 3D photography, together with further developments to transfer Computer Tomography (CT) and Magnetic Resonance Imaging (MRI) scanned data to 2D CAD and solid modeling data as a basis for medical product development;
- Limited Production technologies through silicone rubber moulding, spin- and vacuum casting;
- Mould-making and injection moulding technologies;
- Light manufacturing platforms for larger scale prototyping of industrial machines and processes.

7. IMPACT ON RESEARCH, INDUSTRY SUPPORT AND TECHNOLOGY TRANSFER.

Following its initial proposals to the NRF during 1995/1996, the proposed manufacturing research initiative has developed into an NRF funded

Research Niche Area (and accredited with "developed" status) focusing on Integrated Product Development (IPD) that now boasts several NRF-rated researchers. Although the research participation can still expand, a sustainable number of individual projects are funded on a multi-year basis.

Furthermore, the RNA has managed to expand its funding base to participate in strategic government programmes such as THRIP, the flagship programmes from the AMTS, the Light Materials Development Initiative (LMDI), the Medical Research Council (MRC) and Tshumisano/DST funds. Much of these were only possible through showing the interest from industry in the (applied) research results delivered by the RNA.

Last mentioned forms a case for ongoing funding from the Tshumisano Technology Stations Programme, as the research results are transferred and diffused to impact on industry's (predominantly SMEs) capabilities to be competitive players in the global product development arena. This is possible both through intervention of academics with industry, as well as industry access to the available technology platforms. As can be seen from the graph presented in Figure 2, CRPM's technology platform and support is not an "academic monopoly", but through constant involvement with industry, the majority (approximately 90%) of these machines (even though in a simpler form) has been adopted and is now owned by private industry. This also came as a result of CRPM proving the applicability thereof and impact on competitive product development. Having both the research activity and technology platforms available, it also implies that CUT students are being trained in extremely scarce and strategic skills, and once again offers the institution a competitive advantage to compete for and participate in strategic government initiatives, such as DST's Internship Programme, and the Fablab initiative, aimed at technology transfer and promotion of Science Engineering and Technology (SET) to individuals. Figure 4 shows the research foci, whilst Figure 5 shows the support base for research development, as well as the transfer channels of the research activity, resulting in a two-way flow of support and outputs.

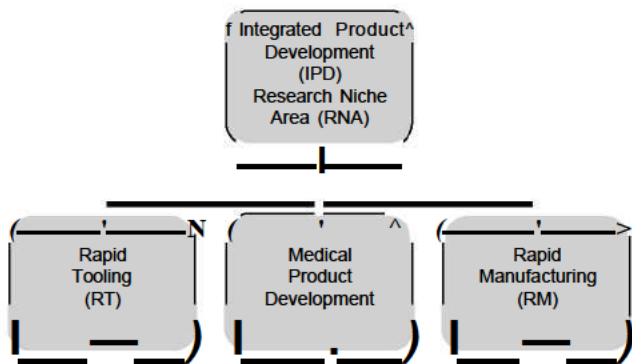


Figure 4 - Integrated Product Development Research Foci

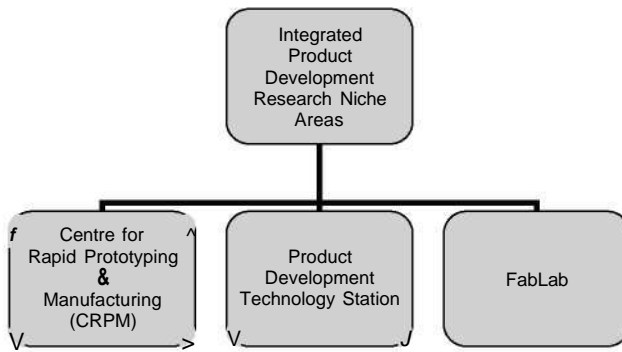


Figure 5: Integrated Product Development Research and Technology Transfer Structures

8. FUTURE CHALLENGES

CRPM has managed to move from a late adopter (late in terms of international activities) to an internationally recognised unit, with some of the latest equipment available, rarely found in universities internationally. Its unique range of available equipment and funding structure/support-base, makes it a highly sought-after unit for any university, whilst its achievements are being viewed internationally as nothing short of remarkable. Figure 6 shows the current strategic research foci (as well as supportive research within the Faculty of Engineering, Information and Communication Technologies), together with the expected research outcomes.

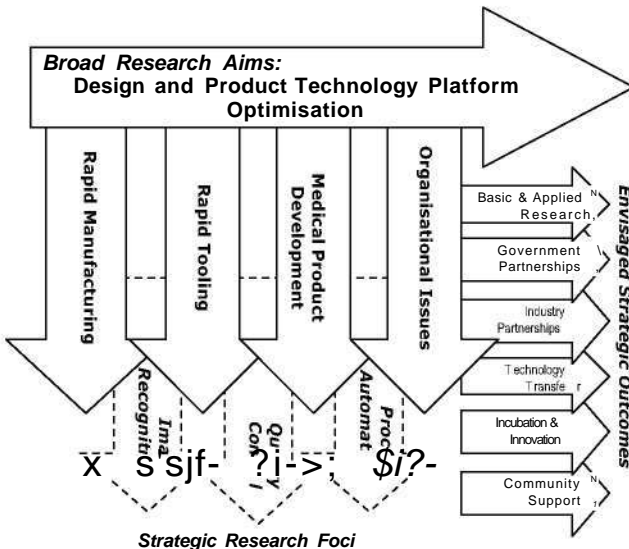


Figure 6: Research foci and expected research outcomes

Although a comprehensive activity with undisputable strategic outcomes, two major challenges still face the further/strategic development of CRPM, namely *Educational Development* and further *Strategic Investment in Infrastructure*.

Educational Development

Additive manufacturing technologies are receiving limited exposure in the undergraduate programmes, and this needs to increase. Whilst ample opportunity exist to curricula unique undergraduate programmes or at the very least enrich existing curricula to become manufacturing oriented, further development may even lead to a partly taught masters degree with specialisation in Product Development.

Strategic Development of Infrastructure

As can be seen from the achievements listed above, the résumé of current technology platforms is comprehensive, with some of the latest technologies being available. Further to the past drive for infrastructure development, it is an internationally recognised fact that RP has moved beyond its initial "fast concept manufacturing" phase, into being used more and more as final or real manufacturing method. This has started a Rapid Manufacturing (RM) culture, meaning that any number of products can be manufactured directly from CAD, without spending any time or money on tooling development (where the decisive factor ultimately is a function of complexity of the design, the material and the required volume per time unit). Current processes offer a range of materials such as epoxy resin, nylon, aluminium/nylon compounds and brass infiltrated steel and tool steel matrices, acceptable as final engineering materials, dependent on the end-use. RM also redefines the traditional design principles, as virtually no design limitations are imposed by the manufacturing process followed. RM typically fits products of which the complexity is high, production rate is low (and spread over time) and applied in high value-added environments, such as the automotive, aerospace and medical product development industries (Wohlers, 2001). It also offers a unique selling point in that "complexity comes for free" (Dickens, 2005).

Whilst some duplication in existing technologies (and which can widen the application focus) is possible, the demands set by direct manufacturing through additive manufacturing technologies are serious, and would necessitate expansion of research activities and associated infrastructure into materials science and quality control - especially from the viewpoint of producing parts directly for the medical, automotive and aerospace industries, which predominantly operate in various ISO environments. It is envisaged that in-house capabilities be developed to do inspection and measuring, in parallel with material sampling and testing. New technology is often popular and exciting, until an unpredicted failure occurs. Although this may happen with any conventional process, enough case studies and manufacturing data are available to simulate, model and predict outcomes and failures associated with conventional technologies, and much of the existing manufacturing technologies are accredited within ISO specifications. Hence, it poses a

challenge to collect enough information to back up design processes and to establish a history of recognised and successful application case studies, which could be referenced for new/further applications, and which may even be used as arguments in a court of law.

It can be concluded that without any doubt, the future of additive manufacturing applications is an exciting one, and in parallel, that infrastructure development will have to continue. The nature of infrastructure development however, will definitely change to include conventional technologies such as testing and measuring equipment. In a certain sense (and quite ironically as well) the research development wheel has made a full turn in moving away from conventional (and almost historical) Mechanical Engineering Science research to a digital product development and manufacturing world, and now relies on proven/conventional (basic) Mechanical Engineering Science to excel into a new era.

9. ACKNOWLEDGEMENTS

Very often, one overlooks the contributions of funding agencies such as Tshumisano, the NRF, THRIP, AMTS and government departments such as the DST and DTI. Furthermore, industrial partners and Science Councils that collaborate with us are giving tremendous development and marketing support to the CUT.

To become a national and international player on that level, a coherent team is necessary, and acknowledgement to team players often does not happen.

The author would thus like to acknowledge all the relevant team players that contributed to making the mentioned outputs possible, starting with the OTM team, the CRPM, Technology Station and Integrated Product Development Research teams and personnel involved, as well as support from the Office for Research Development, together with management structures within the Faculty of Engineering, Information and Communication Technologies - and more specifically Proffs Jordaan and Masu in their respective management roles.

Finally, the employer (*read CUT*) is not always acknowledged for allowing personal growth and development, taking risks that become rewarding initiatives, and creating an environment conducive to producing the outputs. Such outputs require a personal effort/dedication, but definitely are not possible without institutional support.

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