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INFUSING ADDITIVE MANUFACTURING EDUCATION WITH APPLICATIONS: AN INDUSTRY-CENTRIC APPROACH

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ABSTRACT: This paper details how Nanyang Polytechnic has applied industry-centric approach in training its students and industry personnel with relevant additive manufacturing technologies infused with real industry applications. It also briefs on its additive manufacturing journey of capability development, industry engagement and applied R&D activities over the last 15 years in tandem with the changing needs and manufacturing landscape in Singapore. It ends with case studies to demonstrate the impact, value-adding and benefits to industry of our additive manufacturing competencies.

1. BACKGROUND

Additive manufacturing (AM), often referred to as 3D printing or direct manufacturing, is the direct fabrication of three-dimensional (3D) components and products from a digital model, employing technologies that deposit material layer-by-layer successively. Since its emergence 30 years ago, additive manufacturing has evolved into a significant, pervasive technology with application markets including rapid prototyping, rapid tooling, direct component manufacturing, and maintenance and repair. It enables the manufacturing industry the capability to produce geometrically complex, low to medium volume production components in a range of materials with substantially compressed lead time. Additive manufacturing technology is now expected to exert a profound impact on manufacturing sectors as it has the potential to vastly accelerate innovation, reduce time to market, minimize materials and energy usage, and cut down waste (Bourell *et al.* 2009).

Additive manufacturing is not new at Nanyang Polytechnic (NYP), Singapore. Since 1995 NYP has recognised this as a potential disruptive technology and was one of the first sites in the region to leverage on possibilities offered by rapid prototyping/tooling technology. Over the last two decades, NYP has since built up solid capabilities and accumulated vast industry experiences in the full-spectrum of the technology, including rapid prototyping, rapid tooling, direct manufacturing and hybrid tooling by employing wide-ranging processes, such as direct metal laser sintering, polymer sintering, fused deposition modelling, stereolithography and vacuum casting. It has established strong reputation amongst the MNC and SME industries, such as aerospace, biomedical and precision engineering, and many of whom we have supported in scaling up their manufacturing value-chain, evolving into high-value manufacturing and maintaining competitiveness in the globalised business environment.

Rapid Prototyping

NYP first embarked on its AM journey with rapid prototyping process to support the national Original Product Development initiatives and also our new diploma programme in Industrial Design (Figure 1). Some of the earliest AM components in Singapore were created at NYP and they were engaged by local industry for the purpose of employing them as visual aids and

presentation models. Prototype models help increase comprehension of a product design over its 2D counterpart, and they are still the compelling AM application and now it expands to functional prototypes for fit and assembly. Industrial applications at this stage were mainly for consumer, defence and medical products.

Rapid Tooling

The success of prototyping led to the subsequent development in the area of rapid tooling technology to support local contract manufacturers to upgrade to OEM manufacturing. Rapid tooling is the combination of rapid prototyping technology with conventional tooling practices to produce parts of a functional nature from CAD data in shorter time and at a lower cost than traditional machining methods. NYP employs direct metal laser sintering process for the rapid production of plastic injection mould inserts from binder coated metal. Application examples include metal tooling inserts for plastic injection moulding of audio component, medical parts and prosthesis fixture.

Figure 1: Development of additive manufacturing technology at Nanyang Polytechnic

Hybrid Manufacturing and Rapid Manufacturing

To fulfil the new needs of our industry and also to support our applied research and new diploma programme, hybrid manufacturing is developed to integrate both AM process and CNC machining techniques. It has been successfully applied to the rapid fabrication of prototype moulds with built-in conformal cooling channel network. Rapid manufacturing done in parallel batch production can provide a more significant edge in speed and cost compared to alternative manufacturing techniques such as plastic injection moulding. Rapid manufacturing can be applied for custom parts, replacement parts, short run production, and low volume/high mix production.

Direct Digital Manufacturing and Remanufacturing

With the improving material quality, decreasing process cost, and growing awareness of the benefits of additive processes, direct digital manufacturing is now the fastest growing AM application (Scott *et al.* 2012). Instead of producing prototypes for visualization, design verification, testing and analysis, it produces the functional components, personalised products on demand, low volume/high mix production from a wide range of different materials.

Additive re-manufacturing is another advantageous solution when a long lead time or expense is associated with procurement of new parts, or traditional maintenance and repair approaches are not enough to replace worn or damaged parts.

2. AM CAPABILITIES & APPLICATIONS AT NYP

In the Future of Manufacturing (FOM) master plan announced in March 2013, the Singapore Economic Development Board (EDB) has identified 3D printing as one of two types of technological advancements that are redefining global manufacturing competitiveness and that Singapore needs to be actively involved so as to create new growth opportunities in the manufacturing and engineering sectors. EDB will set aside \$500 million over the next five years to support the FOM plan that will develop new and disruptive technologies such as 3D printing. EDB's AM Vision 2020 is to develop Singapore as the key AM Hub for Asia.

In tandem with EDB's FOM programme development roadmap and leveraging on the strong AM expertise and accumulated experience, NYP has recognised the importance of a pervasive ecosystem of additive manufacturing and has further consolidated its AM resources and capabilities under its newly set-up Additive Manufacturing Innovation Centre (AMIC) which will focus on 3 key areas of development: design for AM, technology development and enhancement of AM processes.

Table 1. Additive manufacturing processes at Nanyang Polytechnic

Process	Materials	Build Size (mm)
Stereolithography Apparatus (SLA)	Accura Xtreme (ABS Similar) , Si60 (PC Similar)	260 x 260 x 260
Selective Laser Sintering (SLS)	Duraform Polyamide (PA)	350 x 350 x 600
Direct Metal Laser Sintering	Stainless Steel, Maraging Steel	250 x 250 x 185
M2 Cusing Metal Laser Sintering	Ti, Al, Inconel	250 x 250 x 280
Fused Deposition Modelling (FDM)	ABS, PC, PC-ABS, ULTEM	900 x 600 x 900
Cube 3D Printer	ABS, PLA	140 x 140 x 140
U-Print	ABS	140 x 140 x 140

AMIC Infrastructure

The key objectives of AMIC are to support the training needs and maintaining the relevancy of our existing and new PET and CET programmes and secondly to support the needs of our industry in sustaining their global competitiveness. As such, AMIC's programmes and activities are very much industry-driven and its core competencies are closely aligned with the needs of Singapore-

based MNCs, local industry, manufacturers and organisations. It's well equipped with facilities for a full-spectrum of AM processes (Table 1) and, under partnership with government agencies, is now in the process of setting up new process facilities and building up advanced capabilities in the area of High Precision/Speed Additive Manufacturing, Powder Based Fusion/Direct Energy Deposition, and Multi-Material Additive Manufacturing.

Capabilities & Fulfilment

The Additive Manufacturing Innovation Centre (AMIC) is one of the specialist centres at Nanyang Polytechnic, which provides educational and developmental training on core competencies in additive manufacturing/3D printing/direct digital manufacturing (rapid prototyping, rapid tooling, rapid manufacturing, rapid fixturing etc.) and innovative product development for its students and the industries (Figure 2). The Centre attracts real-life industry projects that are developmental rather than operational in nature, and hence of high learning value to the students. Over the last two decades, the Centre has provided more than 1,000 AM solutions to over 100 companies and organisations in more than 10 industry sectors.

Figure 2: Core competencies of the Additive Manufacturing Innovation Centre

- **Innovative Product Design, Development and Industrial Design**

The Centre has accumulated extensive experience and capabilities working with industrial partners in consumer and medical product design and development. It is able to provide turnkey product development solutions to transform innovative ideas into reality with product design, engineering, product development, and prototype.

- **Rapid Prototyping & Rapid Manufacturing**

With a wide range of rapid prototyping facilities available including Stereolithography, Selective Laser Sintering, Fused Deposition Modelling, Direct Metal Laser Sintering, Selective Laser Cusing and SolidScape, the Centre is able to develop functional prototype or product in polymer and metal materials. With its deep insights of local and global AM trends, it can provide design for AM advisory services, component re-design clinics, and customised training.

- **Rapid Tooling, Hybrid Tooling & Conformal Cooling**

The Centre has developed and fabricated many rapid tooling inserts for industrial customers. The rapid tooling inserts are built using the Direct Metal Laser Sintering process. Complex conformal cooling channels can be incorporated inside the insert for improvement in product quality and shorter moulding cycle time. With easy access to in-house supporting facilities and capabilities, the Centre is well positioned to provide hybrid fabrication solutions.

- **Rapid Fixturing & Jigs**

Fast and flexible fabrication of jigs and fixtures could be done using additive manufacturing techniques. Direct digital manufacturing of fixture allows manufacturing engineers to respond rapidly to production challenges and product revisions. Complex fixtures could be designed and fabricated in a non-traditional way.

- **Rapid Casting (Vacuum Casting/ Silicone Moulding) & Patterns for Investment Casting**

Vacuum Casting is a process that can be used to create multiple copies of a plastic prototype with greater durability. The Centre has delivered numerous vacuum casting prototypes to industrial customers. Vacuum casting parts can be fabricated in polyurethane, investing casting wax, low melting-point alloy and even dual materials. Direct manufacturing of complex patterns for investment casting allows the customisation of design and nested batch production incorporating complex gating and flow lines.

Applied R&D

Industry segments, especially the aerospace and medical implants industries, are increasingly using additive manufacturing technology to fabricate game-changing high-performance products that were previously not manufacturable. In line with the rapid development of additive manufacturing technology, NYP has been actively engaged in the applied research in processes and design techniques, in collaboration with leading industry partners and by conducting government-funded research projects (NRF, MOE TIF). One of such R&D projects is the development of a knowledge-based design tool for the automatic generation of conformal cooling channel network for mould insets to reduce the design lead time with a focus on optimizing conformal cooling configuration for plastic injection moulding productivity. Some of the existing research areas we continue to pursue are hybrid multi-functional additive manufacturing, 3D embedded conformal cooling mould tool, personalised component part manufacture, and ‘on-demand’ direct manufacturing.

Web-Enabled Ideas to Innovation (i2i) Portal

To accelerate the implementation of additive manufacturing technology, NYP has set up a Web-enabled idea to innovation (i2i) portal to leverage on 3D printing possibilities. It’s an internet-based enabling platform where students, faculty and industry partners can create, co-create, demonstrate and crowd-source innovative product design and development. It is aligned with the emerging development trend in additive manufacturing ecosystem, which may potentially one day change the way how the future products are designed, fabricated, sold and delivered to customers.

3. ADDITIVE MANUFACTURING EDUCATION

Additive manufacturing's layer-by-layer fabrication approach removes many of the geometric constraints imposed by traditional manufacturing processes. To realize the full potential of application and scale up AM capability, engineers must know how to design products for fabrication through additive manufacturing. In this aspect, NYP has engaged final-year project students in real-life AM projects, incorporated process and design for AM methodology in a core module for diploma students, provided design advisory services and clinics, organised workshop and seminars for industry, and conducted outreach programme to secondary students.

Teaching Factory Approach

An accepted hallmark of Nanyang Polytechnic is its unique *Teaching Factory Concept*. The Teaching Factory addresses the hitherto unmet challenge commonly faced by institutions in trying to emulate a real world environment within a typical institutional setting. This innovative training model has won acclaim from industries and academics, both locally and internationally (De Roza, 2010).

In line with NYP Teaching Factory approach to technologist education as a unifying philosophy of teaching and learning, the AMIC setting emulates a real-world work environment on campus to provide final-year project students an authentic experience of the nature of their future work and of the workplace. An important and integral component is industry project work where lecturers and students work closely as a team on real-life industry projects with cost, quality, and reliability and deadline constraints. The Teaching Factory contributes greatly to the creation of an environment for teamwork, innovation, strong linkages with industry and a strong focus on capability development, among many other advantages. It has enabled NYP to forge strong collaboration partnerships in applied research in cutting-edge technology and undertake development projects for the training and development of staff and students.

Project-Based Learning

Project-based learning is a dynamic approach to teaching in which students explore real-world problems and challenges. In the core module of 'Product Innovation & Rapid Prototyping', students are challenged to a product design project assignment from art to part. With this type of active and engaged learning, students are inspired to obtain a deeper knowledge of the subjects they're studying. In addition to process, system and design methodology, students are exposed to extensive topics in design for AM, such as identification of product development opportunities, impact on manufacturing economics, generation of concept which is unique to additive manufacturing, and embodiment/detail design in consideration of process tolerance, finish and build strategies.

Outreach Programmes

NYP has been conducting a range of Advanced Elective Modules (AEMs) for upper secondary school students, including 'Product Design and Development'. This hands-on module provides students the opportunity to explore various aspects of design technology and create innovative 3D models using additive manufacturing process. NYP also regularly organises technology seminars and workshops where industrial practitioners exchange knowledge and share experience so as to broaden the understanding and adoption of AM by various industries.

4. CASE STUDIES

NYP leverages on its industry linkages to provide students with relevant and realistic training in current and emerging technologies & best practices and to facilitate the capability development of its staff. In doing so, NYP also support industry in their R&D and product/services development efforts through collaborative projects.

Hybrid Fabrication of Precision Metal Components

NYP provides optimum AM solutions with its strong and advanced capabilities and holistic hybrid manufacturing skills. This industry project integrates advance manufacturing processes such as direct metal laser sintering, direct rapid fixturing, post machining with high-speed CNC and component parting by wire cutting to produce a batch of high-precision triggers in a short lead time (Figure 3). In consideration of the complex geometry, stringent tolerance requirements and deadline constraint, it is extremely difficult, if not impossible, to achieve the project goal by conventional manufacturing techniques alone.

Figure 3: Direct metal fabrication of functional precision components

Rapid Tooling with Conformal Cooling

As part of its turnkey solutions, NYP provides conformal cooling design, cooling optimisation and simulation (Figure 4), and fabrication of rapid tooling inserts for our industrial customers in injection moulding and die casting industries, and fabrication of embedded channels for other industries. For the rapid tooling inserts, they are built using metal laser sintering processes. Complex conformal cooling channels are designed, optimised and incorporated in the tooling inserts for improvement in product quality and moulding cycle time.

Figure 4: Design and Optimisation of Conformal Cooling for Rapid Tooling

5. CONCLUSION

After many years of innovations and development, the Additive Manufacturing Innovation Centre at Nanyang Polytechnic has evolved, developed and established itself as a competency Centre of Excellence in AM, well equipped with leading edge AM facilities and core competencies in Singapore. The success of our industry-centric approach to AM applications and education has benefited from the strong connections and collaborations with leading AM players & manufacturers, as well as proactive partnerships with industry, research institutions & universities, and government agencies through developmental industry projects, advisory services, customised training, collaborative innovation & incubation, and applied R&D. The Centre will continue upgrading its additive manufacturing processes and scale up its core capabilities to support Singapore's economic growth and train future-ready technologists with relevant knowledge and skills for the needs of industry. Some of new development opportunities are in the areas of re-manufacturing in aerospace, marine and oil & gas industries, new manufacturing possibilities with reactive materials, conformal cooling optimisation for injection moulding, high mix/low volume complex manufacturing, and product individualisation.

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