# The Disruptive Evolution Of 3D Printing

Panda, Biranchi; Tan, Ming Jen; Gibson, Ian; Chua, Chee Kai

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# THE DISRUPTIVE EVOLUTION OF 3D PRINTING

BIRANCHI PANDA*
*Singapore Centre for 3D Printing, School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore 639798*
MING JEN TAN
*Singapore Centre for 3D Printing, School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore 639798*
IAN GIBSON
*School of Engineering, Faculty of Science, Engineering and Built Environment, Deakin University, Victoria, Australia*
CHEE KAI CHUA
*Singapore Centre for 3D Printing, School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore 639798*

**ABSTRACT**: 3D printing, also known as additive manufacturing (AM) is one of the promising technologies that have served as a bridge between digital and physical domains without the need of tooling and human intervention. Its ability to turn digital models into physical objects allows designers to design, scan, share, and send digital representations of physical objects just as they can images or text online. With advancement of material science, this technology has greatly improved and now used for many more applications such as energy, healthcare, automotive and aerospace. Considering these recent applications and rapid growth, experts believe that the 3D printing technologies are highly disruptive and this disruption will continue through 2025. This paper reviews the disruptive potential of 3D printing processes and discusses a recent development, i.e. 3D concrete printing, which will hopefully bring success to building and construction industries in the near future.

**KEYWORDS:** Additive manufacturing, Prototyping, Building and construction, Automation

## INTRODUCTION

The emergence of advanced manufacturing technologies, coupled with consumer demands for more customized products and services, are causing shifts in the scale and speed of manufacturing. 3D printing is one of such advanced manufacturing process technologies which conceives the complete product by selectively adding material layer by layer as per the given CAD model (Gibson et al., 2010). Due to significant advantages in terms of cost effectiveness, lower build times, and flexibility this technology is finding applications in many diverse fields of the today's industries (Figure 1). It seems that prototyping (24.5%), product development (16.1%) and innovation (11.1%) are the three most common concerns of the industries fueling the development of 3D printing.

Past studies reveal that this technology was initially used by artists and designers for verifying their concepts (concept modeling) prior to production level (so called Rapid Prototyping). It was very much helpful for them in reducing manufacturing lead time and thus quickens the launch of

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products to the end-use customers. However along with advancement of material science, it has been greatly improved in terms of dimensional accuracy, surface roughness and mechanical properties and now used for many more applications (Section 2). According to Wohlers Report 2014, the global 3D printing market is now expected to grow from $3.07B (revenue) in 2013 to $12.8B by 2018, and exceed $21B in worldwide revenue by 2020 (see Figure 2)

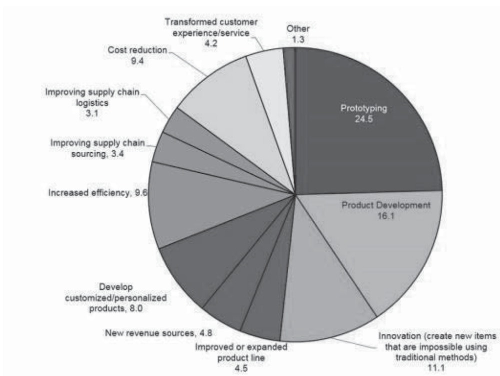



Figure 1. Reasons for pursuing 3D printing [Source: Gartner, 2014]

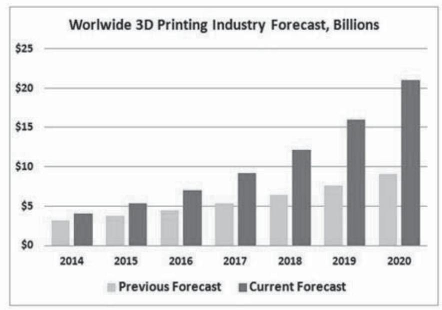



Figure 2. Global forecast for 3D printing revenue [Source: Wohlers Report, 2014]

## 3D PRINTING SYSTEMS AND THEIR APPLICATIONS

The very first patent application for 3D printing was filed by a Dr Kodama, in Japan, in the late 1980's, at which time they were called Rapid Prototyping (RP) technologies. Today there are many varieties of 3D printing systems commercially available in the market. Among them fused deposition modelling (FDM), stereolithography (SLA), selective laser melting (SLM), selective laser sintering (SLS), electron beam melting (EBM) and polyjet are the most widely adopted technologies in the industries (Chua et al., 2003). In terms of materials, a variety of polymers, metals, ceramics and composites can be used in 3D printing. The use of these materials is dependent on the type of process used (Guo and Leu, 2013).

The first applications of 3D printers were in the area of rapid prototyping and then tooling. With regard to prototyping, FDM is found to be the most common and cheapest process being used in many industries. FDM uses molten thermoplastic to fabricate any complex prototypes following the layer by layer deposition process. Starting from business model to fashion, and medical (Figure 3) today FDM is considered as a core part of many production processes due to low cost of the material and good printing accuracy.

Along with this, due to improvements in machine performance, 3D printing technologies have started finding their applications for direct manufacturing rather than prototyping. Certain industries such as aerospace, automobile and military are producing small numbers of highly complex components using SLS and SLM and simultaneously investing to improve their reliability and applicability (Huang et al., 2013; Lyons, 2012). Both SLS and SLM are metal AM systems where laser power can be used to sinter and melt the metal powders accordingly. The parts produced by these processes are normally used for load bearing applications and in many cases it has been proved that metal AM processes stand as an alternative manufacturing method compared to CNC turning and milling (see Figure 4).

Figure 3. FDM made prototypes [Source: http://3dprintingindustry.com/2013/09/17/singapores-nanyang-technological-university-constructs-30-million-am-center]

Figure 4. Automobile and Aerospace part produced by SLM process [Source: http://www.tctmagazine.com/3D-printing-news/slm-solutions-and-eads-partner]

It is most obvious that the medical sector needs highly personalized one-off products for real time applications. The capability of 3D printing seems to be an ideal technique to address this need. This is exemplified by manufacturing of in-the-ear ear hearing aids which has now almost entirely shifted to 3D printing (Sandström, 2015), whilst other applications in orthodontics, prosthetics, orthotics, implants and replacement organs are at various stages of maturity and adoption. Recent developments in 3D bio-printers have revolutionized the medical sector by successfully addressing the need for tissues and organs suitable for transplantation (Murphy et al., 2014). Figure 5 shows some of these recent applications of 3D printing for medical and tissue engineering applications. Apart from this, very surprisingly, 3D printing has also acquired its unique position in food industries by helping them in preparing attractive cakes and chocolate-type edible stuffs (see Figure 6).

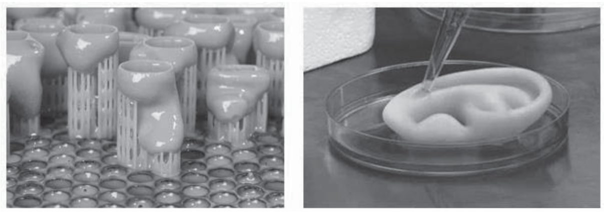


Figure 5. Medical application of 3D printing

Figure 6. 3D printed chocolates

It can be seen from the above-mentioned applications that the 3D printing has a lot influence in recent years and how it has been introduced as rapid prototyping in the middle of the '80s. It has taken 30 years for the technology to get established and be used today for mass production (see Figure 7). This is of course possible due to the development in the technology and material science that are adding quality iteratively to the process. The, following section introduces some of the recent application of 3D printing processes such as concrete printing, which aims to print affordable construction panels in minimum build time and material wastages.

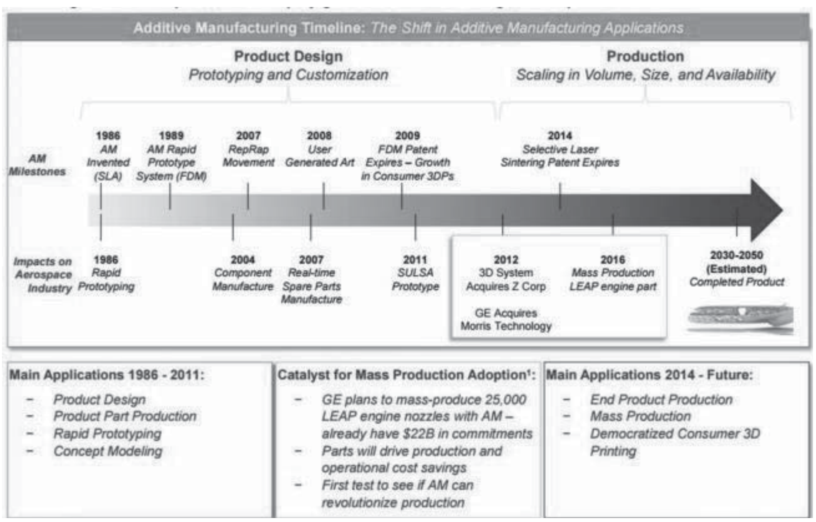



Figure 7. 3D printing adoption time line [Source: Deloitte]

## CURRENT TRENDS AND FUTURE DEVELOPMENTS

In recent years, due to high emphasize on development of new materials, 3D printing technology is spreading across different industries via enabling rapid product development with minimal or no human intervention. MIT glass printing is one among the ground breaking technology which is able to produce transparent glass using layer by layer deposition strategy (Klein et al., 2015). Similarly, development of counter crafting (CC) is also a potential innovation for building and construction (B &C) industries since it uses concrete material to build houses and construction panels in an additive manner (Le et al., 2012). Many researchers are still working on 3D concrete printer to improve its performance and quality during printing. 3D concrete printing works with the same principle as CC, aiming at reduction of labour cost, material wastages compared with conventional construction process. Figure 8 shows concrete printing process at Loughborough University, UK. With global researchers working to explore the possibilities, it is believed that there may be a promising future for concrete printing in the B&C industry.

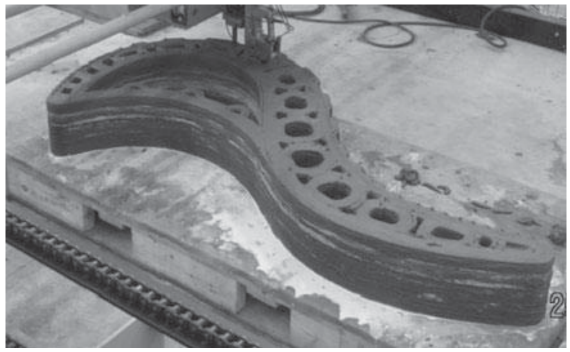
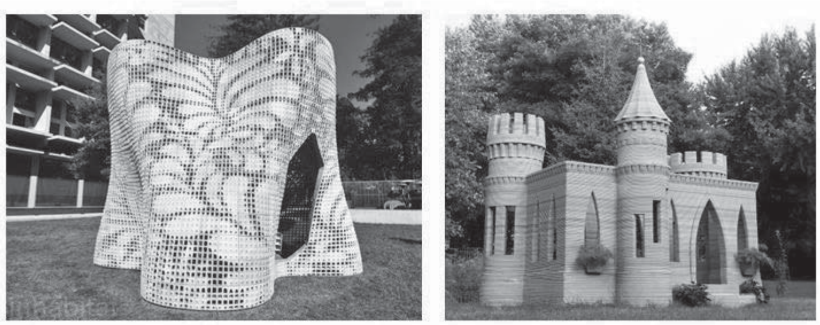


Figure 8. Concrete printing at Loughborough University (Le et al., 2012)

More recently, European Space Agency (ESA) has explored the possibilities of building structures on the moon via 3D printer using the local material, lunar soil. The basic idea behind this lies in the adoption of large scale 3D printer that can use a base material whose chemical and granular composition is very close to the ones which characterize the lunar soil (Cesaretti et al.2014). Apart from creating building and structures, 3D concrete printer could be beneficial for architects and industrial designers. Much more complex design can be printed with varieties of materials in order to enhance the aesthetic features of current construction process. Figure 9 shows some the architect potential of 3D concrete printing process which reflects evolution of 3D printing process has indeed eliminated the shape complexity for architects and designers.



(a) (b)

Figure 9. (a) 3D-printed bloom at UC Berkeley (b) Concrete Castle at Minnesota [Source: http://inhabitat.com/worlds-largest-3d-printed-building-made-from-powdered-cement-unveiled-at-uc-berkeley, http://3dprintingindustry.com/2014/08/27/finally-stands-andrey-rudenkos-3d-printed-concrete-castle]

In addition to 3D printing, in next several years, 4D printing has been considered to move from the research and development labs into actual production roles inside of organizations that are aggressive in their use of emerging technologies (Gladman et al., 2016). One definition of 4D printing is the printing of objects that are capable of self-assembly when exposed to air, water or heat due to a chemical reaction. Also advent of many hybrid AM systems that combine additive, subtractive and formative stages will hopefully eliminate the limitations of 3d printing process and thus making it globally a disruptive innovation for all generations.

## CONCLUSION

The era of disruption in the technology industry is upon us. In 2015, we saw turbulent times in the 3D marketplace, the degree of adoption and eventually disruption will become much more significant as the market matures and moves toward 2020. In this current years, one of the most interesting and emerging technologies that is working in it’s evolutionary way is 3D printing. With increasing number of applications, 3D printing is believed a disruptive innovation of this century and this disruption will continued for a long generation.

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