How companies respond to the emergence of 3D printing technology

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Abstract

In the recent years, the term '3D printing' (known as 'additive manufacturing') is widely used and become very popular in general public. 3D printing has been a functioning technology since 1980s and has generated very high expectations. It can print out physical and solid 3D objects layer by layer using powders, liquids or filaments as the raw materials [1]. Different to the traditional machining process of subtracting materials, 3D printing systems draws on a computer-aided design model to make 3D objects by adding successive ultra-thin layers of the materials [1].

At present, 3D printing is increasingly used to build physical models and production parts in various industries such as jewellery, footwear, toy, architecture, automotive, aerospace, dental and medical industries. A major market trend is increasing consumer demand for 3D printing that requires the manufacture of mass-customization, low-volume and individualized products [3]. 3D printing presents significant potentials to enable companies to think new methods of creating objects and better deal with global manufacturing challenges.

Small and medium sized enterprises (SMEs) are becoming a critical part in the overall manufacturing industry and boosting market prosperity. However, SMEs face some barriers of adoption of 3D printing technology. Furthermore, the strategy to enable SMEs adopt this 3D printing still lags behind. The aim of this paper is to investigate how SMEs respond to the emergence of 3D printing technology, and to identify the factors for implementation of this technology by SMEs. With the emergence of 3D printing technology, what is the strategy to enable SMEs to appropriately adopt 3D printing technology? Are there any drivers that influence the process of applying 3D printing technology within SMEs? This paper mainly focuses on these issues.

Introduction

BACKGROUND

Three-dimensional (3D) printing (known as 'additive manufacturing') can print out physical and solid 3D objects layer-by-layer using powders, liquids or filaments as the raw materials [1]. Different from the traditional machining process of subtracting materials (i.e., milling or drilling), 3D printing draws on a computer-aided design models to make 3D objects by adding successive ultra-thin layers of material [2]. Plastic, ceramics, polymer, metal, and mixture of alloys or even sugar and chocolate can be used to print. Essentially, 3D printers use different technologies to build up models and realize their objects. The most common technologies are selective laser sintering (SLS), fused deposition modeling (FDM) and stereolithography (SLA), for which use melting or liquid materials to that are cured to produce the layers to construct physical objects [2]. Compared to traditional manufacturing, 3D printing is able to improve resource efficiency in ways through introducing more efficient manufacturing systems, implementing new industry systems and promoting new business models [3]. 3D printing has the potential to pave the way for a new era of sustainable manufacturing and its adoption could disrupt the ways that companies operate business and capture value [3].

STRENGTHS AND LIMITATIONS

3D printing offers extraordinary potentials; it enables manufacturers to build products with lower labor requirements and less costs by decreasing large-scale investment in factories and traditional machinery; the use of 3D printing makes it possible to design and develop new products more conveniently and effectively before committing to expensive manufacturing process and tooling [3]; 3D printing demonstrates the ability to efficiently prototype the design to test viability and feasibility of physical parts, thereby helping manufacturers and designers to get feedback faster [3]; since material is added layer by layer, almost the only material needed is used in the production process which reduces the waste; 3D printing offers end users to select from a wide range of design options and easily do much of their own manufacturing [3]. 3D printing is expected to become more cost-effective as production volumes increase. Compared with traditional manufacturing, 3D printing significantly reduces time and resource consumptions, enables low-volume production, eliminates tooling costs, and improves efficiency of new product introduction processes [4]. 3D printing has significant potential to enable companies to think of new methods of creating objects to better address global manufacturing challenges. 3D printing is expected to be used increasingly for producing highly customized items, prototyping, and complex low volume products [4].

Although 3D printing has many benefits, there are some key challenges associated with this technology, when compared to traditional manufacturing. A number of limitations relating to cost, strength, material and precision of product produced need to be overcome before this technology can fully achieve widespread adoption [4]. Costs of the printing machine and material are relatively high and the choice of different materials for 3D printer is very limited [4]. Furthermore, the printing speed process is considerably slower than conventional manufacturing processes, which make it difficult for high-volume production as well; another critical limitation is that 3D printing may raise legal issues about who should be responsible should the component design, printing machine or manufacturing process go wrong. Finally, the full implications on resource use and toxicity remains unclear even though the process itself is material efficient.

AIMS AND OBJECTIVES

Although 3D printing has been a functioning technology since the 1980s and has recently received tremendous attention recently, it has not so far been fully cost-effective for most large-scale commercial manufacturing [1]. However, with positive effects on high customization, product availability, energy efficiency and waste reduction, 3D printing is predicted to revolutionize manufacturing industry, and even create a new industry [1]. SMEs are in a better position to introduce new ideas and are set to become a critical part in the overall manufacturing industry [1]. It would be valuable for SMEs to adopt 3D printing technology to improve their effectiveness and productivity, but SMEs have to overcome some specific barriers such as lack of awareness of this technology and its benefits as well as lack of financial resources. For that reasons, the aim of this paper is to investigate how companies, especially SMEs respond to the emergence of 3D printing technology and to explore the significant barriers hindering its adoption. Additionally, the objectives are to examine the resource use and energy efficiency in this adoption scenario; and to explore the possible roadmap for 3D printing in the manufacturing industry. This paper involves a combination of a critical analysis of literature and a qualitative research study. The qualitative research methods such as semi-structured interviews with managers are adopted to collect detailed and in-depth information and data.

Emerging Trends in Using 3D Printing

INDUSTRY EVOLUTION

In retrospect, digital cameras changed the photography industry, and the advent of iPhone made by Apple Inc. changed the way of communication and even the whole music industry as well. As the digital age comes, people need to rethink about the way of developing and manufacturing products. A major market trend is the increasing of consumer needs for 3D printing that require the manufacture of mass-customization, low-volume and individualized products [4]. The advent of 'Digital Fabrication' will highly change the nature of global manufacturing landscape and enable manufacturing industry to become more connected, personalized and flexible. Particularly, digital fabrication will trigger business model innovation and contribute to low carbon and high efficient manufacturing process [4]. The 3D printing technology has been developed through different stages. Rapid prototyping was at first used by companies in the beginning of 1990s. Rapid tooling became the second stage of adoption. In the late 2000s, as the cost of 3D printing became low enough to directly manufacture final products, it led to the third stage of adoption, which referred to direct digital manufacturing. Direct digital manufacturing directly manufactures end-products without moulds, casts and machining. Furthermore, the fourth stage of adoption is home fabrication which involves consumers manufacture products themselves using 3D printers at home [4]. However, as 3D printer prices are and the technology yet immature, the adoption stage is quite limited. To this respect, there has been much debate about whether 3D printers can take the same place in people's homes as personal computers did, and whether can lead to a widespread home adoption of 3D printers. Therefore, 3D printing follows the same adoption patterns as other disruptive technology such as Internet [4]. (Today's use of 3D printing technology in different applications can be seen in Figure 1.) There is still 33.3 % of companies not implementing 3D printing technology and the adoption of 3D printing technology is limited in the SMEs [4].

BUSINESS MODELS FOR 3D PRINTING

Today's established manufacturing industry systems mainly rely on the mass production infrastructure. Thereby, product-manufacturing process mostly involves large numbers of stock, high labor inputs, massive energy use and tremendous capital investments [5]. 3D printing has the outstanding advantages of enabling manufacture complex freeform geometries as this process is not constrained by the limitations of conventional manufacturing way [5]. 3D printing technology has brought about changes to traditional manufacturing industry and has the potential to enable adaptive business model innovation.

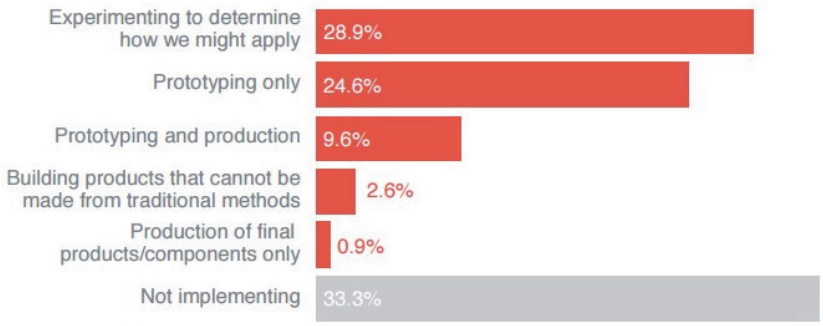

Figure 1. How is company currently using 3D printing technology? (Source: PwC and ZPryme survey and analysis, conducted in February 2014.)

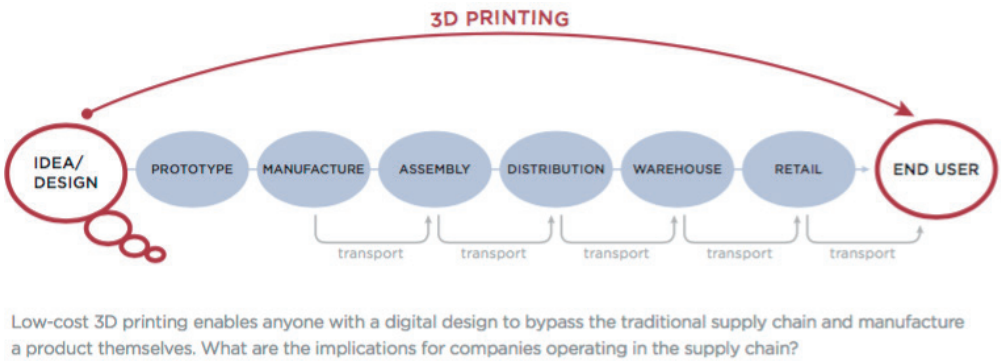

Figure 2. The long-term opportunity for individuals. (Source: CSC 3D printing and the future.)

Therefore, this section explores different business models that companies are currently using to create and capture value through 3D printing technology.

The business model is involving with how company create value, how company capture that value and who they bring value for [5]. The principal business model component for 3D printing is value proposition as 3D printing technology has brought about product and service innovation [5]. Since customers/end users have the opportunity to manufacture products at home or in situ print shops, it will enable mass customization that lead to value creation between customers and firms. Company tend to discover the implications of applying 3D printing on extending product life cycles and closing the loop, which may change the sustainability impacts of manufacturing processes as well [5]. Furthermore, 3D printing can possible alter the whole supply chains and distribution channels thanks to its flexible business model [5] (see Figure 2). For instance, in auto repair shops, people could make specific auto parts on site using 3D printer instead of ordering the items to be delivered by suppliers. Accessories or toys companies can use online 3D printing services to sell their products to customers. This business model is quite efficient as consumers can either print out the products they order at home using their own 3D printers, or have them printed through online 3D printing service then deliver to them directly [5].

In 2005, Adrian Bowyer had developed RepRap, the first open source 3D printer. The business model is to share all the documents, components and plans online under a GNU/GPL license, so users are free to download, produce and sell their items [5]. This innovation led to the creation of large community of enthusiasts and hobbyists. In addition, the current business pioneer in the 3D printing field is MakerBot and its goal is to become an open source 3D printing company. This company believes that the future of manufacturing is to open source for sharing with their users all over the world. This company has created a platform called Thingiverse for end users to upload their own design files, models and ideas for sharing [5]. Therefore, other individual users are able to download and print at home to make personal product portfolios by their own. Another 3D printing service company is Makexyz, which has operated 3D printers over 17 countries including the UK and the US. Makexyz is continuing to expand itself with more 3D printers in more different countries. Makexyz established a platform for home 3D printer owners which help them set up a small business on their own. Such a platform creates an ecosystem for printer owners where they are able to interact with other end users and compete for pricing with other 3D printer owners in different countries for business and products. It is a significant step for local 3D printing markets that Makexyz provides a new way of production process that connect individual resources to a fast growing dynamic network [5]. 3D printing technology can shorten distribution channels and reduce the need for large quantities of inventories as the business model is to supply digital design blueprints rather than real physical products which lead to just-in-time operations for manufacturers.

3D Printing Adoption Within SMEs

SEMS OVERVIEW

SMEs are mainly defined by their total number of employees (typically less than 250 employees) or their annual balance-sheet not exceeding approximately £34 million or annual turnover not exceeding approximately £40 million [6]. SMEs are becoming an important part in the overall manufacturing industry, and also SMEs play a significant role in developing various products and boosting market prosperity. Some noteworthy strengths are that SMEs often have high rates of employment, flexible organization structure, short decision-making processes, and outstanding innovation capabilities; also they have the ability to provide more efficient responses to clients then big firms, which highly contribute to today's economic environment and business world [6]. In terms of the current manufacturing industry situation, SMEs play a vital role in acting as the facilitators for supplying parts and components to large companies [7]. Specifically, SMEs are able to produce components and parts of a final product as at a relatively lower price as if the large companies would do it themselves [7]. Therefore, it is valuable for SMEs to adopt 3D printing technology to improve their effectiveness and productivity as well as strengthen their roles in the manufacturing industry and product development processes.

BARRIERS AND LIMITATIONS

However, many SEMs not even considering this disruptive technology to be implemented into their business. Even though 3D printing has tremendous advantages for production and process, how SMEs respond to this technology is still not fully recognized [7]. In fact, there are some barriers and limitations that hinder the use and adoption of 3D printing technology within SMEs. One of the key factors is the lack of awareness of 3D printing technology. Technically, lack of awareness contains several factors including lack of guidance, lack of resources, resistance to change, unfamiliarity of this technology and benefits [7]. Furthermore, external environment factors such as suppliers, buyers, government regulations and competitive pressures are becoming significant for directly impacting adoption of 3D printing technology within SMEs. Particularly, the role of government is one of the crucial factors to influence the use and adoption of this new technology. Government has the ability to support and facilitate financially the process of technology development in SMEs, and it also provides tax benefits for large manufacturing infrastructure construction [7].

SMEs need more financial support than large companies due to limited ranges of technological competencies and financial resources [8]. If the initial set-up costs of 3D printing systems were too high, most of SMEs would be hesitated to implement this technology. Moreover, due to lack of industrial experiences, outsourcing of 3D printing is becoming much popular for many SMEs sectors. Some other factors of acquiring 3D printing technology and embedding it effectively into business are the knowledge and professional qualifications of the decision makers [8]. In most of the SMEs businesses, the owner's experiences and knowledge highly influence the organization decision in response to new technology such as 3D printing. If the decision makers were lack of technological skills and knowledge, it would largely hinder the adoption of any new technology or innovation development.

At the decision-making stage, it would be beneficial to conduct the SWOT analysis to help SMEs be aware of the current situations of business. Knowing the strengths, weakness, financial circumstances opportunities and threats would help companies effectively response to 3D printing technology by either adopting or refuse it. SMEs are gradually becoming aware of the importance of this key technology for economic development and business prosperity. As 3D printing provides extraordinary opportunities for highly customized product development and efficiency improvement, implementing this technology within SMEs would enable them to build innovative business model and enhance their capacities to effectively deliver products and services [8].

Technology Acquisitions in 3D Printing

The majority of large companies such as automobile, software and pharmaceuticals companies have R&D divisions that are responsible for developing new products or improving of existing procedures or services [9]. SMEs, on the other hand, due to financial constraints, do not have equivalent financial capability to invest in R&D. Therefore, technology acquisition would be more suitable for SMEs as technology acquisition is less expensive and less risky. SMEs can use 3D printing through technology acquisition from external research and academic institutes. SMEs can also establish partnerships or form strategic alliances with suppliers which can provide machines and technical support services. On the other hand, some startups invest in researching on 3D printing technology and developing new 3D printer to make its price lower and more cost-effective as some large companies such HP and EPSON present high aspirations to acquire high-tech start-ups through mergers and acquisitions activities to maintain competitive.

Technology Protection Aspects in 3D Printing

The emergence of open-source 3D printing service has brought several challenges and risks to the intellectual property (IP). 3D printing provides the opportunity for high quality customization to reduce the possibility of some novel products being copied. To encourage new product development, it is very significant that manufacturers and designers can keep generating values and profits from their own intellectual properties. Conversely, the nature of open-source 3D printing models makes it very hard to control and limit sharing of IP. The development and application of 3D printing are often compared with the situations of the copyrights of music or movies on the Internet [10].

Consumers are much likely to use or copy digital files for free. The intellectual values and design ideas should be highly protected. If there were no concrete policy to protect intellectual property rights, patents, trademarks or design rights, the motivation for people to engage in design, research, and development would be highly reduced. Therefore, the regulatory frameworks have to be adjusted to integrate different circumstances associated with the digitalization of ideas and objects. Furthermore, as end users have the ability to access and

share the digital design files on the Internet for free, it would encourage the process of innovation and development of new ideas. However, it may also limit and restrict incentives to invest in design and development of 3D printing blueprints [10]. Therefore, clear legal framework and regulations concerning 3D scanning, digital blueprints and online distribution of ideas have to be established to improve the economic incentives for novel ideas and distinctive products. On the other hand, too restrictive intellectual property regulation could also hinder business innovation in 3D printing field [10]. It is significant to balance the customers' need for open-source service and the investors' need for incentives in intellectual property protection for 3D printing software development. Therefore, it is the responsibility of government policy makers to assign legal liability for any problems that might be caused by 3D-printed products and services [10].

Roadmapping for 3D Printing

3D printing allows manufacturers and consumers to produce technically complex, low-volume, highly customizable products at a profit. Yet some SMEs are unfamiliar with 3D printing technology and less likely to adopt and use 3D printing technology [7]. A 3D printing roadmap is able to help SMEs and other businesses to efficiently develop a strategy to adopt 3D printing. This roadmap framework includes five steps as follows [11].

First, SMEs conduct the SWOT analysis to identify the current situations of business and then to establish the initiative to identify figure out how can implement 3D printing within the organizations, and how this technology can affect companies [11]. The second step is to invest in the technology. Particularly, SMEs need to know what specific hardware or software is required to set up a 3D printing initiative. Then, to figure out the financial resources should invest in 3D printing based on the company size and capability. Furthermore, it is necessary to understand where to source this disruptive technology to make or buy [11]. The third step is to create a network. It is beneficial for SMEs to obtain key partnerships with large companies and suppliers to solicit competitive resources and capabilities. Also, SMEs can find out some public sector grants to overcome financial scarcity. The fourth step is to change the organization. As the barriers facing by SMEs are lack of guidance, lack of resources, resistance to change, unfamiliarity of this technology and benefits. Therefore, to start and run a 3D printing initiative, SMEs should figure out what kinds of key skills and knowledge should be obtained. SMEs should identify the need of changing organizational structure and creating new business units to effectively adopt and use 3D printing. Moreover, companies need to know the key stakeholders who can help create and capture values from 3D printing [11]. The last step of the roadmap is to implement the innovation. At this step, the critical point is to develop the effective ways to bring 3D printing innovations to the market. 3D printing can be implemented to manufacture highly complex and customizable products for customers. For product-based SMEs, these products should fit within the existing product range [11]. Furthermore, SMEs should be clear about the target customers and market, thereby coming up with well-designed strategies to deliver novel products and services.

Research Methodology

This paper involves a combination of critical analysis of literature and a qualitative research study. The search strategy was to identify the relevant database and keywords to ensure objectivity in assessment of wide range of sources [12]. Key database were identified to cover a diverse range of publications from academics and industries. The scope of this research has taken in many new topics outside of the conventional manufacturing domain, which incurred many challenges. The aim of this paper is to explore how companies, especially SMEs, respond to the emergence of 3D printing and to identify the factors for implementation of this technology within SMEs. Therefore, the qualitative research methods such as semi-structured interviews with managers are about to adopt to collect detailed and in-depth information and data. A semi-structured interview allows new ideas to be brought up [12]. The key justification for conducting qualitative research is to explore the levels of managers' understanding of 3D printing and the challenges they're facing of integrating 3D printing into their existing industrial systems. Therefore, a purposive sample of senior managers who have valuable experiences about this issue will be targeted for the research. The next step will proceed to collect the subtle comments of managers and conduct case studies in the context of adopting 3D printing within SMEs. Furthermore, the barriers and drivers of implementing 3D printing will be identified through the interviews with senior managers from various industrial sectors. One of advantages of using qualitative research methods is to benefit from unexpected findings and have a better position to view the linkages between events and activities [12].

Future Work

The results of the study provide a background for setting future research directions. This is ongoing research intended to be completed by interviews with SMEs to gain new insights of the diffusion of 3D printing within SMEs. For instance, the

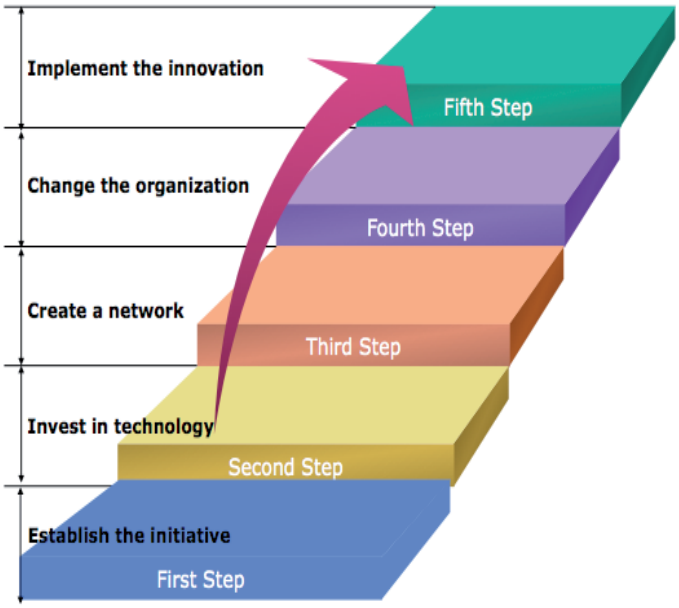

Figure 3. 3D printing – strategic roadmap. (Source: Deloitte, Disruptive manufacturing the effects of 3D printing.)

challenges of integrating 3D printing into existing industrial systems, the challenges of applying 3D printing to create new industrial systems; the energy and resource consumptions for adoption of 3D printing within SMEs; also the business strategies of creating and capturing values from 3D printing by existing SMEs. Other research methodologies can be used to address the remaining gaps. System engineering methodology that employs mathematical and simulation methods to help SMEs quantify the energy and resource consumptions by adoption of 3D printing. Based on that, companies are able to better understand the perceived value that a potential customer may hold. Further research will continue to focus on how SMEs have dealt with 3D-printing issues and the energy efficiency of 3D printing within SMEs.

Conclusion

The advent of 3D printing provides a new paradigm for manufacturing industry and highly changes the nature of global manufacturing landscape [12]. 3D printing can shorten distribution channels and reduce the need for large quantities of inventories as the business model is to supply digital design blueprints rather than real physical product, so it can lead to just-in-time operations for manufacturers. It can be predicted that 3D printing will be widely used to manufacture technically complex, low-volume, highly customizable products within companies. Thanks to the development of 3D printing printers and base materials, the costs have decreased tremendously to make 3D printing become more accessible to companies across all the sectors to trigger market evolution.

SMEs are considered as the key source for economic development worldwide and are becoming more important in manufacturing and industrial businesses. SMEs have high rates of employment, flexible organization structure, short decision-making processes, and outstanding innovation capabilities. Therefore, they are capable of providing more efficient responses to clients then big firms. The adoption of 3D printing technology within SMEs can enhance their capacity to offer high-customized products and strengthen their roles in the advanced manufacturing processes. However, there are still some barriers and limitations that hinder the use of 3D printing technology within SMEs. Resolving these barriers is the key for SMEs to effectively use this disruptive technology. The full implications on resource use and toxicity remains unclear even though the process itself is material efficient. Furthermore, the strategic technology roadmap is offered to start a 3D printing initiative and create new business models and network. The fundamental step is to obtain key skills and knowledge and adjust organizational structure to adopt 3D printing. Also, companies should be clear about their target customers and potential markets, and then develop a strategy to deliver distinctive products and services. In order to fully maintain open source service and capture value for consumers, the intellectual property rights and design ideas need to be highly protected. Without full protections, the motivations for people to involve in creative design and research would be significantly compromised. Therefore, government policy makers should make appropriate legal framework and regulations to protect IP rights and improve the economic incentives for new ideas and distinctive products generation.

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