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# Opportunities And Impacts Of Additive Manufacturing: A Literature Review

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# OPPORTUNITIES AND IMPACTS OF ADDITIVE MANUFACTURING: A LITERATURE REVIEW

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**ABSTRACT**

Additive manufacturing industry has experienced tremendous growth in the last decade. This paper aims to address the lack of insights and systematic research by investigating opportunity and impact of potential economic benefits of AM. Our results show that the number of publications in the AM research has increased exponentially since 2009. The papers have been identified into five themes: applications, country, opportunity, economics and social. Our results show that there are an increasing number of papers that investigate economic and social benefits of AM.

*Keywords:* Additive manufacturing, 3D printing

## INTRODUCTION

Additive manufacturing (AM) or 3D printing is a process of joining materials to make objects from 3D model data [35]. The object is created through successive layers of materials using computer-generated design to reproduce a digital model through consolidation of materials with an energy source [19, 36, 43]. Petrick and Simpson [36] argue that AM environment allows consumers to interact directly with producers in a manner that economies of scale and high volume centralised production is no longer necessary. In fact AM results in localisation of both production and sourcing. AM is viewed as a disruptive technology that has the potential to replace conventional manufacturing processes [40] and the AM industry is projected to increase from $3.07 billion in 2013 to $12.8 billion by 2018 [13]. The advantages of AM include low-volume production, lower cost production, responsive production, shorter supply chains, democratisation of production and optimised design [40]. AM was initially used for rapid prototyping purposes, however there have been greater number of finished products (such as biomedical implants, pharmaceutical products, customised sport gears) produced in the last few years.

The expansion and growth of AM industry in recent years have resulted in extensive publications in the research area of AM. However publications in AM have focused on the engineering and technical development aspect of AM technology such as selective laser sintering and dynamic magnetic compression. Little research has presented an overview of potential economic and social impacts of AM. This paper aims to address the lack of insights in this direction. A systematic search is conducted to identify publications that investigate or research into potential and opportunities of AM as disruptive technology in the society. This paper presents the outcome of a preliminary systematic literature search in AM.

## METHOD

A literature search was conducted in September 2015 using three databases: ProQuest, Web of Science and Scopus. AM was initially used for rapid prototyping purposes and it was around the period of 2000s that AM has begun to grow. Thus the time limits of literature search were set to the years from 2000 to 2015. Search terms were based on title of publication that consists of ("additive manufacturing" OR "3D printing") and keywords with "opportunities" OR "opportunity". The reason keyword "opportunity" or "opportunities" is selected is to identify papers that report AM as an instrument for opportunity for adoption. Only peer-reviewed and full-text articles written in English are included. As this paper aims to identify research that presents promises and assessing impacts and potential use of AM, only articles that presents survey of current practices, adoption, opportunities, innovation, economy and social benefits of AM are included. Articles that describe AM from the engineering or technological development perspective such as selective laser sintering, dynamic magnetic compression, computer-aided design (CAD), 3D handling software and detailed AM production processes such as in tissue regeneration [12], biomedical implant [23, 45] were excluded. Content analysis was conducted by reviewing the abstract of articles to ensure it fits this criterion. Full-text of papers was reviewed if the abstract did not present sufficient information to determine if the paper meets the inclusion criteria. Figure 1 shows the process flow of the search strategy.

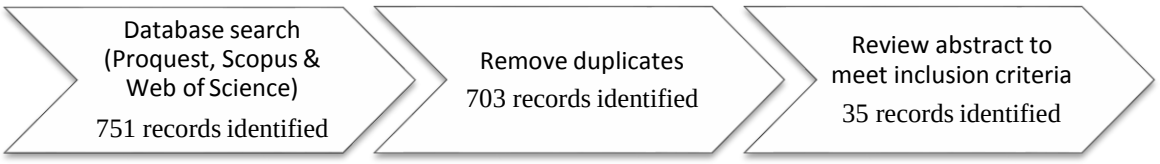


Figure 1. Process flow of the search strategy.

## RESULTS

A total of 751 records were identified from the three databases. There were 703 records after duplicated records were removed. Figure 2 shows the distribution of papers between 2000 and 2015. It is worth noting that the number of records found for 2015 only shows records up to the current search date September 2015. From the graph, it can be seen that from the year 2009 there was an extensive increase in the number of papers published in area related to AM. The abstracts of 703 records were further reviewed to find articles that met the inclusion criteria specified in the search strategy. Of these 35 records were found. Figure 3 shows the distribution of papers that met the criteria between 2000 and 2015.

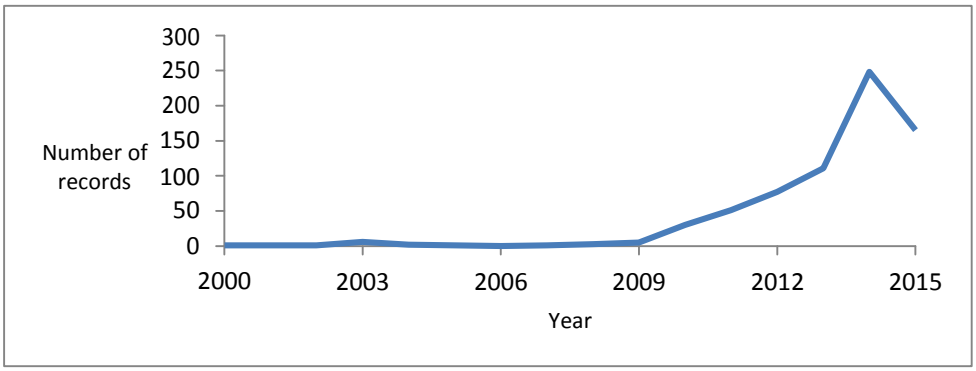


Figure 2. Distribution of records - initial search

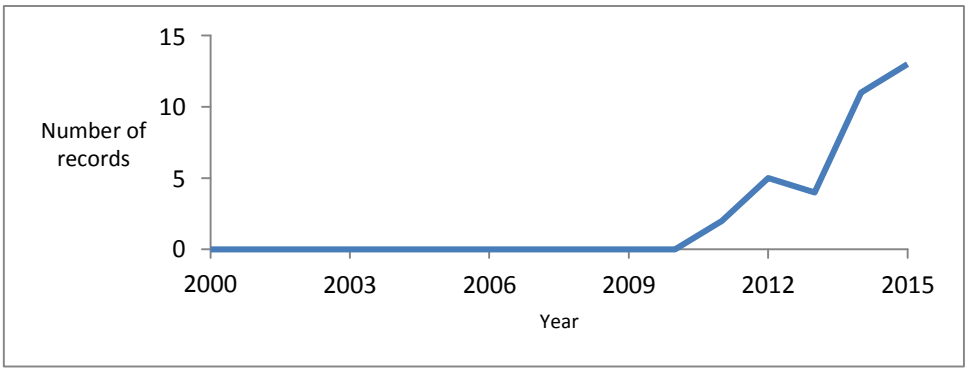


Figure 3. Distribution of records that met the inclusion criteria

Each of the 35 papers was reviewed and each paper is identified into a theme. Five themes were proposed: applications, country, opportunity, economics and social. The applications theme identified papers that discuss the applications of AM such as aerospace, health and medical, food and archaeological restoration. Papers in the country theme report on how AM is used in a specific country. The opportunity theme refers to papers that present findings on insights, ideas, potential and impact of AM. Papers identified in the economics theme presents findings on economic or business models, costing models and supply chain of AM. The social theme includes papers that investigate privacy, intellectual property and environmental impact of AM. Table 1 shows the references identified for each of the themes.

Table 1. Major themes

| Theme | References |
|---|---|
| Applications | Angrish et al. [2], Banerjee et al. [5], Ferreira et al. [18], Harrysson et al. [24], Li et al. [30], Lipton et al. [31], Soe et al.[41], Yeong et al. [49] |
| Country | Bhattacharjya et al. [7], Campbell et al. [10], de Beer [16], Kianian et al. [27], Rahim et al. [38], Wong [48] |
| Opportunity | Ahuja et al. [1], Campbell et al. [9], Gress et al.[21], Ma [33] |
| Economics | Atzeni et al. [4], Campbell et al. [11], Cozmei et al. [14], Dawes et al. [15], Khajavi et al. [25], Liu et al. [32], Mellor et al. [35], Piller et al. [37], Weller et al. [47] |
| Social | Appleyard [3], Bem et al.[6], Burkhart et al.[8], Forrest et al. [20], Kietzmann et al. [28], Kurfess et al. [29], Mani et al. [34], Valpreda [44] |

## DISCUSSION

The AM industry has experienced tremendous growth in the last decade with the global markets for AM products and services has grown to over $2 billion [40]. Extensive research has been reported on engineering and technological challenges to improve materials used, machine speed, CAD programs and product reliability. Limited research reports on potential, opportunities and assessing impacts of the use of AM on the society at large. Results from literature search show that the number of publications in the AM research has increased exponentially since 2009, however most of the published papers are focusing on the engineering and technical perspectives. Of the 703 articles retrieved, only 5% of the papers discuss potential and opportunity of AM in a wider community. Of the 35 papers reviewed, there are an increasing number of papers that investigate economic and social benefits of AM in relation to improved product value [11], social inclusion [6] and job creation [27]. The impact of AM on supply chain has also been explored [15, 25] and the benefits of AM in other sectors (besides engineering and manufacturing) has also been presented. For example there is an increasingly positive impact of AM in medical application [5, 24]. The economic impact of AM at firm [4], industry [10] and country [20] levels are reported. Social and environment issues such intellectual property [28, 29] and environmental impact [34] are also being reported.

AM has its roots in the development of rapid prototyping in the 1980s with technology advances in stereolithography. Then advancement in processes such as laser sintering and material deposition extrusion in the early 1990s has resulted in AM technology being used in more sectors and demands for applications began to grow. Within the last five years, advances in new material and improved AM processes through development of new generation of 3D printers have resulted in AM gain popularity as the technology matures. Industry from different sectors have realised the potential of using AM to further develop their own products to enable cost savings and new optimized designs. As AM progresses, the future of AM will gain widespread practices.

One of potential impact of AM that has been reported is in reshoring. Many manufacturing firms in the developed countries such as America and United Kingdom have begun to seek alternative options of moving their offshore manufacturing base to their home country as the manufacturing costs in the offshore developing countries have substantially increased [46]. In recent years, there is a geographical shift of reshoring high value manufacturing activities back to the manufacturing firms' home countries by moving towards value-added production rather than mass production [42]. Value-added production enables firms to focus on mass customization such that smaller batches of a wider variety with each product can be tailored to meet customer's need. Value-added production has also resulted in falling production cost and thus lesser reliance on economies of scale [22, 26, 42]. Reshoring high value manufacturing activities back to the home countries can lead to the firm moving up the value chain as well as creating shorter and more responsive supply chains and improving communication with customers [17, 42]. In a study reported in the State of Profession Study of 2012 [46], 29% of the respondents claimed that their company will use 3D printing and AM, in particular for electrical equipment and appliance assembling company. Thus the literature review in this paper can contribute to the understanding of opportunities of AM in the wider industry sector. By gaining insights into potential opportunities of AM it is able to guide researchers to understand adoption of AM.

This research has its limitation that only three databases were used to conduct the literature search. More databases should be included in the study to ensure completeness of the search. It is proposed that further research can be conducted to investigate adoption of AM using Rogers' model of diffusion of innovations [39]. Based on current result, it can be observed that the number of AM publications identified in this study exhibits an S curve of adopter distribution. There are five stages of innovation decision process in Rogers' model: knowledge, persuasion, decision, implementation and confirmation. The adoption of innovation cannot occur without learning and knowing about the innovation, in this case the AM. An investigation on publication trends of potential and opportunity of AM in the industry is useful to help the wider industry community to understand and to gain insights of how AM is used and applied in the wider industry sector.

## CONCLUSION

The AM industry has experienced tremendous growth in the last decade. Extensive research has been reported on engineering and technological challenges to improve AM and 3D technological advancement, however limited research reports on potential, opportunities and assessing impacts of the use of AM on the society at large. This research attempted to fill this gap and the outcome of a preliminary systematic literature search is presented. Our results show that the number of publications in the AM research has increased exponentially since 2009. The papers have been identified into five themes that include applications, country, opportunity, economics and social. Our results show that there are an increasing number of papers that investigate economic and social benefits of AM. Further research is proposed to investigate adoption of AM using Rogers' model of diffusion of innovations.

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