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The barriers to the progression of additive manufacture: Perspectives from UK industry

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ABSTRACT

Additive manufacture (AM) is receiving significant attention globally, reflected in the volume of research being carried out to support the commercialisation of the technology for industrial applications and the interest shown by government and policy makers in the technology. The lack of distinction between 3D printing and AM, as well as the portrayal of some highly publicised applications, may imply that the technology is now firmly established. However, this is not the case. The aim of this study is to identify the current barriers to the progression of AM for end-use products from an industrial perspective and to understand the nature of those barriers. Case study research has been conducted with organisations in the UK aerospace, automotive, defence, heavy machinery and medical device industries. Eighteen barriers are identified: education, cost, design, software, materials, traceability, machine constraints, in-process monitoring, mechanical properties, repeatability, scalability, validation, standards, quality, inspection, tolerances, finishing and sterilisation. Explanation building and logic models are used to generalise the findings. The results are discussed in the context of current academic research on AM. The outcomes of this study help to inform the frontiers of research in AM and how AM research agendas can be aligned with the requirements for industrial applications.

1. Introduction

The progression of additive manufacture (AM) has received international attention, with collaborative research, technology translation and commercialisation initiatives existing across the globe; America Makes in the USA (National Center for Defence Manufacturing and Machining, 2017), and High Value Manufacturing Catapults and the National Centre for Net Shape and Additive Manufacturing in the UK (Innovate UK, 2017; MTC Ltd, 2017). It is estimated that the UK has the potential to capture an annual £3.5 billion of the global economic market by 2025 (AM-UK Steering Group, 2017a). Although some technology leading companies have progressed their applications of AM under the scrutiny of the media, they do not form a true reflection of the technology readiness level of the technique across all industries. The reality is that the maturity and incidences of commercial AM products are highly specific to the industry, application, and company. In the past 5 years, multiple reports have been published by government and collaborative research and industrial initiatives to understand the economic importance, strategic and challenges associated with progressing AM in the UK and Europe (AM-UK Steering Group, 2015; AM-UK Steering Group, 2016; AM-UK Steering Group, 2017a; European Commission, 2014; European Technology Sub-platform in Additive Manufacturing, 2014; Innovate UK, 2015; Li et al., 2016a; Technology Strategy Board: Special Interest Group, 2012).

Comparably the amount of academic literature which addresses the challenges preventing the wider adoption of AM in industry, is extremely low, these are summarised in section 2. Ford and Despeisse (2016), present a case study analysis on the sustainability of AM in industry, drawn from open access information: company websites, news sources and academic publications. Niaki and Nonino (2017) and Dwivedi et al. (2017) implement direct consultation with industry into case study methodology to analyse the impact of AM on businesses in Italy and the USA, and India, respectively. More specifically in the UK, the AM-UK Steering Group (2017a) have recently presented the AM-UK National Strategy. This strategy includes ranked and brief summaries of the challenges facing industry, collected from workshops and online surveys consulting 123 organisations (AM-UK Steering Group, 2017a; AM-UK Steering Group, 2017c; AM-UK Steering Group, 2017d). To date, an academic study has yet to present an in-depth explanation on why

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industrial applications of AM have not progressed to more end-products in the UK economy.

This research aims to identify, from the perspective of UK industry, what the barriers to the progression of AM are, and why these barriers exist. This study answers these research questions using a case study approach and analytical generalisation of interviews with employees of 11 industrial organisations across the aerospace, automotive, defence and medical device industries. In addition this paper presents the industrial case study findings in contrast to the current status of research endeavours. The research satisfies a critical gap in the current knowledge presented by roadmaps and research literature. It identifies why the barriers exist, promotes a deeper understanding of the problems, and frames the difference between what is required by industry and what is currently active in research.

2. Additive manufacture

2.1. Overview of the technology

Additive manufacture is defined as the "process of joining material to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies" (ISO/ASTM International, 2015). Broadly, AM encompasses all additive techniques applied to all materials. The term 3D printing can be interchangeable with AM, particularly in the media. Within the research and industrial communities 3D printing tends to refer to polymer and non-enterprise based printing whereas AM is the expression used in a production-context. Rapid prototyping (RP) is often interchanged with 3D printing, however, it is generally applied to the manufacture of geometrically accurate models suitable for demonstrative, i.e. prototyping purposes. The accelerated development of 3D printing is demonstrated succinctly by the Gartner Hyper Cycle for Emerging Technologies (Gartner, 2017), progressing swiftly from technology trigger through to slope of enlightenment between 2010 and 2013, distinguishing between consumer and enterprise printing in 2014 and 2015 and progressing onto 4D printing (the 3D printing of components which are responsive to external stimuli over time (Khoo et al., 2015)) in 2017. The development of metallic, ceramic, polymeric, composite and biocompatible AM materials which are geometrically and mechanically functional have taken considerably longer to progress.

The industrial options for AM are constrained by the commercially available technologies. Metal AM falls into four categories: powder bed fusion, direct energy deposition, metal binder jetting and sheet lamination. The most promising technologies for the AM of structural parts are powder bed fusion and direct energy deposition. Powder bed fusion technologies selectively fuse feedstock on the build area using thermal energy (ISO/ASTM International, 2015). This technique encompasses selective laser sintering (SLS), selective laser melting (SLM) and electron beam melting (EBM). The literature has investigated the application of SLS, SLM and EBM to medical devices (Cox et al., 2016; Hayashi et al., 2005; Shah et al., 2016; Traini et al., 2008; Wauthle et al., 2015) with increasing applications foreseen in the aerospace industry (Olakanmi et al., 2015; Uriondo et al., 2015). Direct energy deposition, uses a focussed thermal energy source to fuse materials as they are being deposited (ISO/ASTM International, 2015). This technique includes direct metal deposition (DMD) where the material is deposited in blown powder form and Wire and Arc AM (WAAM) where the feedstock is in wire form. Although deposition methods are well regarded for the potential impact they offer to industry (Frazier, 2014; Gu et al., 2012; Williams et al., 2016), to date research literature remains more focused on fundamental processing dependant parameters (Dinda et al., 2009; Ding et al., 2015a; Szost et al., 2016; Wang et al., 2015). Research literature reviews of AM predominately focus on a selected technology (Ding et al., 2015b; Flynn et al., 2016; Gu et al., 2012), a parameter within the process (Spears and Gold, 2016; Thompson et al., 2016; Yang and Zhao, 2015), a material (Gorsse et al., 2017; Mertens et al., 2017) or a certain application (Femmer et al., 2016; Guo and Leu, 2013; Li et al., 2015; Uriondo et al., 2015). An example of two broader reviews are those of Gao et al. (2015) and Gardan (2016).

2.2. Industrial implications

There are few academic publications focussed on the industrial implications of AM. Frazier (2014) presented a balanced review which incorporated both process, business and environmental considerations drawing on academic literature, industrial reports and conference presentations. Thomas (2016) discussed the economics of AM using a systematic break down of the supply chain and Huang et al. (2013) reviewed the impact of AM on society. Baumers et al. (2016) contextualised the economic implications resulting from an inter-process cost analysis between EBM and direct metal laser sintering. Schmidt et al. (2017) broached the impact of laser based AM on various industrial sectors. Gausemeier et al. (2011) conducted a selection of workshops with industrial and academic partners to identify current and potential applications of AM, and presented a matrix of success factors for the application of AM throughout a selection of industries. Pinkerton (2016) expanded on this data, with a brief explanation on the barriers to AM, however, the supporting literature is predominately research based as opposed to directly from consultation with industry.

Niaki and Nonino (2017) undertook a case study analysis of organisations in Italy and the USA, to assess the impact of AM on business competitiveness. Dwivedi et al. (2017) used an interview approach to derive the relationships and hierarchy between the barriers to AM in the Indian, automotive industry. Ford and Despeisse (2016) presented the opportunities and challenges of AM from industrial case studies extracted from company websites, news sources and academic publications. The portrayal of AM in the media is focussed on pioneering companies with high publicity products. Whilst the promotion of AM is crucial for industrial endorsement, encouraging collaboration, investment and public engagement, it can misrepresent the uptake, maturity level and magnitude of the sustainability benefits (Ford and Despeisse, 2016) of the technology across all industries and products. The reality is that the uptake of AM varies between types of industry (Pinkerton, 2016). This study confirms that a large amount of applications remain in the research and development phase (Ford and Despeisse, 2016), an observation which is supported by government initiatives aiding the translation of AM into industry (Innovate UK, 2017; MTC Ltd, 2017; National Center for Defence Manufacturing and Machining, 2017).

The most pertinent literature on the industrial implications of AM in the UK is The Additive Manufacturing UK National Strategy 2018–2025, which maps out strategies to overcome challenges in the following areas: cost/investment/financing, design, IP, protection and security, materials and processes, skills/education, standards and certification and test and validation (AM-UK Steering Group, 2017a). The strategy was proposed by the AM-UK Steering Group (2017b). The AM-UK Steering Group initially published a positioning paper (AM-UK Steering Group, 2015) and followed up by developing the National Strategy (AM-UK Steering Group, 2017a) in conjunction with industrial consultation. The methodology behind the industrial consultation is outlined in two update reports: data was collected via three workshops and also an online survey, gathering perspectives from 123 organisations across 15 industries (AM-UK Steering Group, 2017c), analysis of the data involved ranking and summarising the barriers (AM-UK Steering Group, 2017a; AM-UK Steering Group, 2017d).

3. Case study protocol

This research was designed as a multiple case study analysis. The unit of analysis was defined as engineering organisations, represented by an informed employee, and the geographical homogeneity was restricted to the UK. The inclusion and exclusion criteria are outlined in Table 1. These criteria allowed, informed participants to represent organisations