Inspiring Great British Manufacturing

Report Title: **The significance of the EPSRC DfAM Research Network for UK industrial companies**

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Executive Summary

In this report, the significance of the EPSRC Design for AM (DfAM) Research Network is discussed, from the perspective of industrial companies who are interested in adopting Additive Manufacturing.

The Research Network was established in late 2020 and since then has created a members database, held a series of networking events and has established connections to professional bodies and standards organisations.

UK manufacturers now have access to specific and relevant information on DfAM and a focal point for networking with other professionals and the UK academic community on topics related to their aspirations for design and additive manufacturing.

The Network also presents an opportunity for collaboration with other academic disciplines to create the next generation of industrially-focused AM design tools.

Contents

Abbreviations

3DP	3D Printing
4DP	4D Printing
AI	Artificial Intelligence
AM	Additive Manufacturing
ANSI	American National Standards Institute
BSi	British Standards institute
CAD	Computer Aided Design
CDfAM	Computational Design for AM
CDT	Centre for Doctoral Training
DfAM	Design for AM
DfM	Design for Manufacture
DfPP	Design for Post-Processing
EPSRC	Engineering and Physical Sciences Research Council
EWF	European Welding Federation
IAMQS	International Additive Manufacturing Qualification System
KRT	Key Research Theme
NCAM	National Centre for Additive Manufacturing
NDT	Non-Destructive Testing
RF	Radio Frequency
ROI	Return On Investment
TRL	Technology Readiness Level
TWI	The Welding Institute

1 Introduction

The MTC helps UK companies adopt advanced manufacturing technologies including Additive Manufacturing (AM). The MTC is home the National Centre for Additive Manufacturing (NCAM) and at the NCAM for the past 10 years we have been researching and supporting the industrialisation of AM Design.

We recognise the importance of UK academia in this endeavour and have strong ties to academia through our founding partners as well as through sponsorship of PhDs and EngDs and involvement in Centres for Doctoral Training (CDTs) such as the CDT on Topological Design. We see that there are still significant barriers to industry adoption of AM, many of which are design-related. There are also tremendous applications that AM hardware is capable of which are not yet fully exploited by industry. We were therefore glad to have the opportunity to support the EPSRC DfAM Research Network.

As members of the Network Steering Committee, we offered to write this report on how the Network's output is relevant to UK manufacturing companies.

2 The need for Design in AM

AM has been available for over three decades and in that time has matured from a prototyping technique into a tried and tested manufacturing process. Adoption of AM globally has been steadily growing and is expected to continue doing so. In 2024 the global market for AM is projected to increase by approximately 20% [1]. Overall though, AM's share of the global manufacturing market today is lower than anticipated [1 p.118], [2, p.9], [3]. A number of industry observers have commented on the reasons for this, and an overarching theme is the need for a more realistic portrayal of AM by its proponents. Potential users of AM are aware of what the technology is and can do. They may have an interest but want to see a clear plan for a Return on Investment (ROI) before they make a sizeable investment in the technology [4]. A tangible business case is therefore a key requirement for the adoption of AM.

In the UK the uptake of AM has been growing in line with the rest of the world, but more slowly than the global average. The UK market slipped from 6.9% of the global AM market value in 2015 to 4% in 2022 [5]. The UK's additive manufacturing users group, Additive Manufacturing UK (AMUK) held several workshops in 2023 to ask members about the challenges they face with all aspects of AM. The identified challenge areas were design, materials & processes, inspection, testing, standards, commercial IP and data, skills and education and supply chain.

A summary of the feedback specifically related to design is shown in Table 1.

DfAM challenge descriptions
Lots of 3D designs poorly optimised for 3D printing
Products in Polymer designed for Injection. Restricts manufacturing design
AM is a bolt on for many engineering courses, needs to be a standalone course. Not enough understanding of design for AM or design for applications.
Narrow approach to cost analysis – no adoption. (design for AM is proposed as a solution)
The expectation of management that AM can be used as a direct replacement to conventional manufacturing. Lack of AM adoption as it can't directly replace conventional manufacturing. Furthermore, people can't decide for AM so the technology can't be up taken.
How many people are exploring the art of the possible with regards to designing to fully take advantage of AM**?** If businesses aren't doing this, then why?
DfAM is about the integration rather than design rules
Understanding what Standards apply to AM and what can be introduced.

Table 1 - Feedback relating to Design from AMUK workshops, as expressed by participants of the AMUK workshops [5]

The significance of design on the AM business case depends on how the company plans to create wealth from AM. The primary ways of doing so are shown in Table 2:

Use	Likely ask of a designer
Prototyping	DfM*1 knowledge
Production aids	DfM knowledge, thinking 'outside the box'
Legacy parts and digital inventories of existing products	MfM*2, AM material properties
Short run production / bridge tooling	MfM, AM material properties
New product opportunities (complex, efficient, customised etc)	DfAM*3 knowledge and experience, specialist software, understanding of AM material behaviour, DfPP*4

[1] DfM - Ensuring the part is suitable for manufacture by an AM process

[2] MfM – Modification of a part to make it manufacturable by an AM process, as opposed to designing a product specifically to be manufactured by AM

[3] DfAM – Designing to leverage AM without the fallback of using conventional manufacturing

[4] DfPP – Design not only for the build process but also the post-processing and inspection steps that parts (almost always) need

Table 2 – primary business cases of AM

All of the above applications need design, and the importance of good quality design to the business case increases as we move down the list. AM prototyping is reasonably straightforward for any company that already uses Computer Aided Design (CAD). It's fairly easy to access AM DfM guidelines and design and print a prototype at a 3DP printing bureau to gain a benefit. Moving down the list, the impact (positive or negative) of design on the AM business case increases, as does the need for a greater commitment to design from the company. To create valuable AM products, designers will need new skills, specialist design and simulation software and to be able to integrate the DfAM workflow into their company's existing processes.

From the above we can surmise that there is a need to present realistic solutions for using AM to UK manufacturing companies and provide access to the skills and design tools they will need. This will positively influence their decision on whether to adopt AM and furthermore, maximise the value they can take from using the technology.

3 A summary of the EPSRC Research Network

The Network was set up and run by Loughborough University and Lancaster University. It was funded by the EPSRC, to run for three years from October 2020 and was granted two extensions, taking it to December 2023

Among the objectives of the Network was: (i) providing a forum for the DfAM community to speak collectively to funding bodies and standards agencies and (ii) promoting the wider importance of DfAM and raising its profile. The Network implemented three primary strategies to achieve its objectives:

1. Creation of a members directory
2. Establishing relationships with external (i.e. non-academic) bodies
3. Promotion of DfAM through a series of topic-based events, as listed in Table 3

Material focus	**Tools and methods**
Metal based AM processes	Computational Design Tools
Polymer based AM processes	4D printing
Application focus	**Wider themes**
Printed Textiles	Responsible Design for AM
Printed Electronics	Design for Education
Redistributed Healthcare	

Table 3 - The nine Key Research Themes of the Research Network (MTC grouping)

The topic, or Key Research Theme (KRT) owners hosted workshop events which seeded knowledge and encouraged collaboration between the attendees. Over the 2 years of the Research Network, over

100 presentations were given at these events (recordings publicly available at UK Design for AM Network – YouTube).

The members directory numbered 163 people at the time of writing this report, a significant percentage of whom have industrial affiliations.

During the three years of the network, links were established with professional bodies and organisations: EWF, EU AM-platform, ANSI, TCT360, 4D printing society, Design Society.

4 Discussion of the Network output

The KRT events were attended by a mix of academics, manufacturing companies, software and hardware vendors and professional organisations. Most of the presentations touched on themes that were directly relevant for industrial users and would-be users of AM.

4.1 Exploiting AM

4.1.1 The AM business case

The entry point for many companies is the business case. Many of the KRT events had a focus on the end use of AM and the practical ways it is being used, plus considerations around AM product introduction. Some of the highly relevant presentation topics included:

- How Land Rover and Airbus use AM
- The design workflow for personalised products
- Certification challenges in AM
- Regulatory framework considerations for AM in healthcare
- The economics of AM material supply
- Needs-driven AM ROI scenarios vs casting, machining and forging
- AM for diverse applications including wiring harness manufacture, RF components, batteries and electric motors
- Made Smarter funding opportunities

4.1.2 Design skills/training

A KRT dedicated to DfAM education explored not only academic qualifications, but workforce skills and apprenticeships in the context of the UK National Curriculum for AM. The International AM Qualification System (IAMQS) was introduced by the European Welding Federation (EWF) as were the benefits of Maker Spaces when it comes to encouraging ‘out of the box’ thinking that DfAM needs, that could also be useful in a workplace environment.

The KRT also looked at skills for future design tools. DfAM increasingly makes use of computational DfAM (CDfAM) tools such as generative design or implicit geometry to create the designs that are required by the company’s AM business case. To avoid creating another barrier to adoption, education

& upskilling will need to incorporate CDfAM training [6]. A common request we have from customers at the MTC is to demonstrate how to create a complex design that exploits the 'design freedom' of AM, for example a heat exchanger or a cellular material. Essentially, the customer wants to avoid upfront upskilling costs for specialist software and this is a barrier to adoption. As an extreme example of this trend in CDfAM, PicoGK by Leap71 is an AM design tool where the designer creates geometry by writing code. It is a very versatile way to get value from AM, by designing efficient structures or generating adaptable part families for example, and it also demands a completely new skillset.

4.1.3 Standards

Standards are often thought of as more relevant to manufacturing process chain than to design but in the case of DfAM they are essential for the industrialisation of the design process. Through the KRT, industrial attendees see the value of being involved in standards development to help create the standards they will use in the future.

The Network has made a valuable connection to The American National Standards Institute (ANSI). ANSI, together with America Makes maintains an AM Standardisation Roadmap [7] which is a barometer of industry needs for the adoption of AM. It has a section dedicated to design and mentions several key areas that need development:

- Design guides
- Design tools
- Design for specific applications
- Design documentation
- Design for verification and validation
- Design for anti-counterfeiting

The Network also has links with Eujin Pei at Brunel University, who chairs the BSi AMT/8 Committee on Additive Manufacturing.

A related development from the Network is a collaboration between Imperial College, TWI and the MTC on an ASM handbook chapter on modelling and optimization for DfAM.

4.2 Design tools

A question in one of the AMUK workshops was 'is anyone exploring the art of the possible?'. This very valid point highlights the need to listen to the pull of industry in terms of applications and education, but also to promote applications that industry may not have thought of.
As noted in the KRT on Computational Design, AM hardware capability is largely underexploited by the manufacturing industry. There are currently very few AM products for example that have hierarchical and/or graded material compositions even though AM hardware can make them, and it is in part because they are very difficult to design, validate and verify. The same is true for auxetic structures, shape memory alloys or 4D Printing (4DP) materials objects, which were demonstrated in the KRT events.

Although the AMUK members' feedback didn't explicitly request better design tools, it would be fair to say that AM design tools are still a restriction for the art of the possible [8]. At the same time, in the UK we have a track record of developing cutting edge AM design software (for example LimitState, FullControl, Gen3D, AdditiveFlow, Within, ToffeeAM) many if not all originated in academic research. They all unlocked one or more aspects of AM's untapped potential. In some cases, the tools have matured over time as standalone software and became 'ready' for industry (e.g. Limitstate). In other cases, international software or hardware vendors – such as Altair, Autodesk or NanoDimension - acquired them to incorporate them into their commercial offerings.

It would make sense to try and capitalise on the outputs of UK academic endeavours. Design software and services accounted for 37% of the global AM market in 2023 [9]. The UK also has four AM machine manufacturers. Working together, the UK ecosystem could develop software solutions that let a user make the most of the machine and offer them to industry. As we have seen, they are looking for turnkey solutions: 'idea in, physical part out'. The development of the design tools should include not only using the software itself but also the workflow integration and data traceability requirements, for certification and standardisation.

An example application for a design tool would be one for architected materials. The Innovate UK Materials and Manufacturing vision 2050 report [10] emphasises the importance of design and materials. It talks about conventional materials and conventional manufacture but also opens the door to DfAM, which is literally about making materials during manufacture, by designing materials using localised mesostructures and/or material compositions. Some UK companies are already working on the material side of this big opportunity [11]. Academia is very active in this area, for example Queen's College who are researching machine learning for creation of damage tolerant cellular structures. This approach can lead to new, industrially useful AM materials. An industrialised design process would need to exist for these materials, that considers how validation of designs and verification of the material structures will be carried out and allows for design for the whole AM process chain not just the build. So there is a sequence of capabilities that would need to be developed to make this design capability accessible to industry. Such a design tool would provide big opportunities for UK companies to innovate and is something the Network could coordinate development of.

4.2.1 Informed Design

'Informed design' is a term to describe the scenario where a designer is making design decisions based not only on the product specification and knowledge of DfM requirements but also on a plethora of information that might come from a number of downstream data sources. Historical manufacturing, testing and product-use data can be parsed with simulation data to create an optimal design solution. This concept doesn't only apply to additive manufacturing, but is an ideal fit for AM since it is a digital manufacturing process. This approach has been described in literature [12] and in the KRT [13].

In the world of AM there is already activity ongoing to use the digital thread and Artificial Intelligence (AI) to improve the effectiveness of the manufacturing process itself. This was the theme of a talk by Autodesk in the Computational Design workshop. The digital twin can also be used in conjunction with Non-Destructive Testing (NDT) and test data to speed up certification of parts and processes. By extending the concept, the AM design process can benefit from the same data sources. In our opinion, there is an opportunity to use the digital twin (empirical data) in combination with simulation data to inform the design process and drastically improve the effectiveness of AM designs. 'Informed' designs would be more likely to print without failures, they would be as close to optimal in terms of material use, with less fudging around material properties, they would be easier to inspect. The designer could also use downstream data from historical use of similar products and from sustainability databases to inform decisions during the design stage and create optimal products.

This is another example of a cross-disciplinary problem whose solution would require collaboration between disciplines such as simulation, machine learning, data science, NDT and AM hardware. The Network again is ideally positioned to coordinate and promote the relevant research.

5 Summary

The Network was established in 2020 primarily to improve DfAM research in the UK, but we have seen that its outputs are also relevant for industry. Topics that were cited as barriers in the AMUK survey which included design tools, applications, training and standards were all points of focus for the Research Network. As such it has established itself as a point of reference for DfAM, opening communication with UK industry, demonstrating what is available now in AM design and what is coming through from low Technology Readiness Level (TRL) research. Industrially relevant collaborative initiatives have resulted between the Network and ANSI, TWI, MTC and AMS. Industrial companies now have a point of contact via the Research Network website to reach out to academics and fellow professionals and associations and undertake collaborative research.

From the perspective of academia there is an opportunity, from the workshops with industrial companies, to work with them as the future end users of the technology, towards achieving a common goal. In addition, the UK can take advantage of its expertise in developing design software to create the next generations of AM design tools.

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