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A Case Study of the development of the UK's Additive Manufacturing National Strategy 2014-2017

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A Case Study of the development of the UK's Additive Manufacturing National Strategy 2014-2017

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Abstract

The importance of the role of Additive Manufacturing (AM) technologies in company, regional and national level manufacturing activities is becoming clearer as AM technologies mature and levels of adoption in a wide range of application areas increase. In response, many nations have developed national strategies (or 'public technology strategies') to help align public and private sector activities to address barriers to further development and adoption, and coordinate resources to address opportunities. This paper describes the process by which the UK developed its national strategy for AM. The operational details of the activities undertaken through four stages over the period 2014-2017 are explained and analysed. The aim of the paper is to share the details of how this strategy was developed – in a changing political and economic context – such that others involved in the development of similar strategies might learn from this experience.

Keywords: additive manufacturing; national strategy; public technology strategy.

1. Introduction

Additive Manufacturing (AM) technologies have received considerable attention in recent years from both industry and governments as their core characteristics are perceived to enable business model transformation, increased competitiveness, and manufacturing activity relocation in a wide range of sectors [1, 2]. The diversity of the technologies and breadth of potential application areas present an extremely complex environment for targeting support to overcome barriers to their adoption. In response to these challenges, some nations have developed and published explicit strategies [3], actions plans [4], roadmaps [5, 6] and run workshops [7] to help align public and private sector activities to address barriers to adoption and coordinate resources to address opportunities relating to AM. Some of these have been done within broader advanced manufacturing [8] or digital manufacturing [9] strategies.

The processes by which such public technology strategy activities are developed are not always clear, and there is much variation in approaches. For any emerging technology, the dynamic nature of the underpinning science and technology, and the complexity of the economic and social systems to which the strategy relates make this an inherently challenging activity. There are many examples of national strategies for emerging technologies that have been made publicly available (e.g. [10-12]). While such publications typically describe the broad process undertaken to develop the strategy, few reveal the operational details of the challenges faced, and how these were overcome. The aim of this paper is to share the operational details of how one strategy was developed – in a changing political and economic context – such that others involved in the development of similar strategies may learn from this experience. The remainder of this paper is structured around four sections. We first describe the methodology used for this paper and provide a brief overview of the underpinning AM technologies. The core of the paper then focuses on a description of the activities undertaken through the four phases of the process of developing the strategy. The paper concludes with comments on the key lessons that can be extracted from this case study, and suggests areas of further work.

2. Methodology

This paper uses a single case study method, drawing upon a range of primary and secondary sources of quantitative and qualitative evidence. The case method was selected because it is a common and useful method for exploring ‘how’ questions related to contemporary events [13].

The primary evidence was data captured from an on-line survey of stakeholders, multi-organisation workshops, and participant observation by the two authors who were also members of the strategy's Steering Group. The secondary sources of evidence were published reports, presentations and articles relating to AM development and adoption. The details of how data was captured and analysed is given in the description of the relevant phases of the process in section 4.

3. Additive Manufacturing

AM technologies can be described as "*a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies*" [14]. AM encompasses a multitude of different technologies, each at differing levels of technological maturity, offering the use of different materials, with different quality outputs[1]. AM can be classified according to the method of material supply into liquid based, solid based and powder based systems [15]. **Error! Reference source not found.** shows a selection of the most common AM processes.

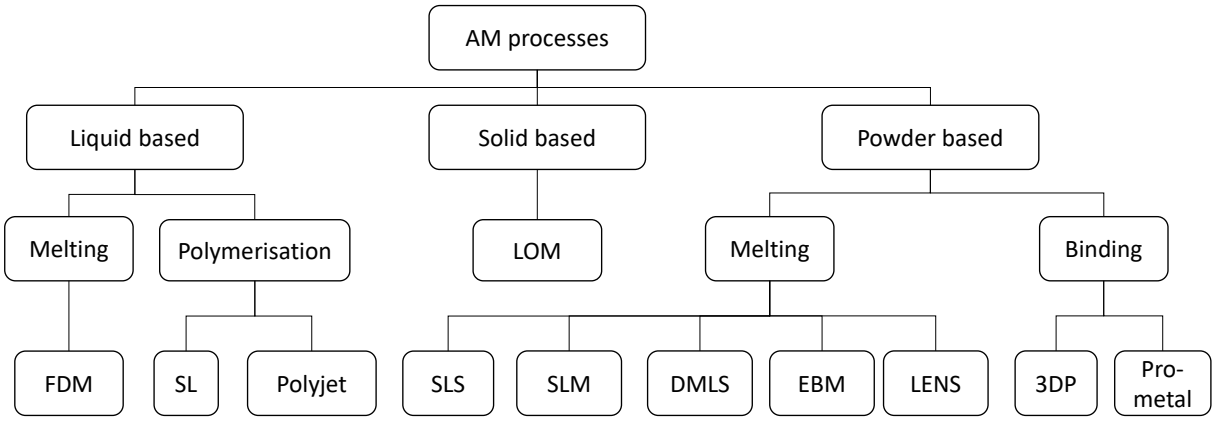


Figure 1: Key additive manufacturing technologies based on the input material and fusing method.

As the technical performance of AM technologies has improved, their use has expanded from applications predominantly for rapid prototyping to the production of final parts with applications across a variety of industries. AM has many characteristics that distinguish it from traditional subtractive, forming and casting processes, aside from the approach it takes to fabrication. AM technologies offer: new design freedoms, enabling entirely new geometries to be produced; a digital nature making manufacturing directly from 3D models possible; net- and near-net-shape part production capabilities; and, being tool-free, it enables more flexible manufacturing (adaptable and

[1] Composite materials are sometimes considered as a form of additive manufacturing but were not included within scope of the strategy development process described in this paper. The UK's national strategy for composite materials can be found at https://compositesuk.co.uk/system/files/documents/Strategy%20final%20version_1.pdf.

lower changeover costs and time). Furthermore, some scalability challenges do not apply to AM and the process can result in lower waste resulting from fabrication [16]. These advantages combine to enable the use of AM for manufacturing bespoke customised products on demand that are economically attractive relative to conventional mass production methods [17].

However, there are numerous challenges to these technologies being fully 'industrialised' and delivering on their full potential. Some of these challenges stem from the relative immaturity of AM technologies in comparison with other manufacturing processes and the lack of widely accessible fundamental understanding on the performance of different combinations of AM processes, materials and applications [2]. There are also other challenges and barriers inhibiting their adoption and diffusion including issues of intellectual property [18], costing [19], quality assurance and production planning [20], and skills [21], some of which would be common to any emerging manufacturing process, others more specifically relate to the digital nature of AM technologies [9].

As a technology for the production of final parts, AM has been adopted in certain niche markets for small production runs of high value, high complexity products. These include traditional craft sectors such as jewellery; medical applications where personalisation to the human body is highly advantageous; and the prestige automotive and aerospace sectors where structural components can be designed and produced with enhanced attributes [1]. The range of applications is expected to grow as AM technologies improve and confidence is raised through the visibility of demonstrations of AM implementation from leading manufacturers such as GE and Rolls-Royce, and the relative ease with which some sectors (such as hearing aids [22] and dental implants [23]) have successfully adopted these technologies. These applications have led to an increased awareness of the benefits and challenges of developing and deploying AM technologies.

Having provided this technological context for AM, the following sections presents the details of the process by which the UK AM National Strategy was developed.

4. The process of developing the UK AM National Strategy

The process of developing the strategy can be divided into four phases: (1) Initiating activities; (2) Initial evidence gathering; (3) Strategy development - Part I; (4) strategy development - Part II. These activities spanned a period (2014-2017) that saw a change of national government from Conservative/Liberal Democrat coalition to Conservative. Figure shows how these phases linked to the changing political context.

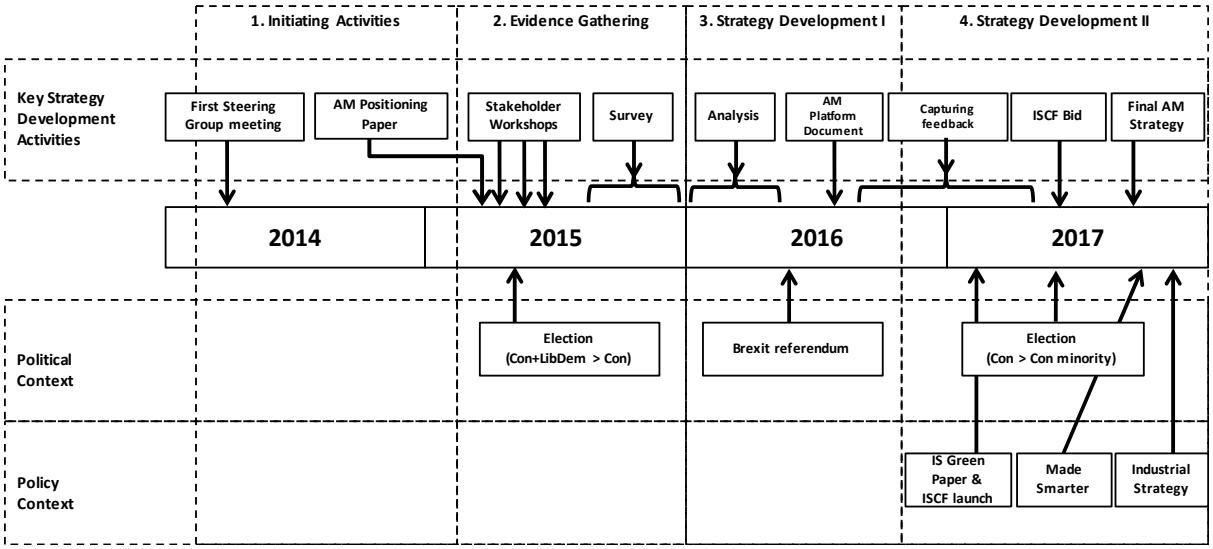


Figure 2: The key strategy development activities and relevant political and policy context

4.1. Initiating activities (early 2014 – early 2015)

Discussions about establishing an AM strategy in the UK began in 2014, following the publication of a series of reports by various industrial and policy groups [24-26]. The idea of developing a strategy to improve the UK's ability to create and capture value from the deployment of AM was not initiated directly by the UK government but emerged during a meeting of academics and industrialists in April 2014. A key output of these discussions was an agreement to form a UK AM National Strategy Steering Group to bring together representatives of the then Department of Business Innovation and Skills (BIS), InnovateUK, industry and academia to explore the scope and process of developing an AM strategy for the UK. The initial membership of this Steering Group is given in **Error! Reference source not found.**. A key initial activity of this group was the researching, writing and publication in 2015 of a 'positioning paper' that described the role of AM in the UK economy [27]. This paper presented an overview of the broad challenges facing AM from both a technological and economic perspective, presented three scenarios for intervention, and emphasised the need for "[..] *a government supported UK Strategy for rapid, high value industrialisation of AM*" [27].

Table 1

Name	Role (at outset of strategy process)	Organisation
Chris Carr (Chair)	Deputy Director (Manufacturing, electronics and professional & business services)	Department for Business, Innovation and Skills
Phill Dickens	Professor of Manufacturing Technology	University of Nottingham
Brian Greenwood	Deputy Head (Materials & Engineering)	Department for Business, Innovation and Skills
Neil Mantle	Additive Layer Manufacturing Executive	Rolls-Royce
Clare Marett	Head of Manufacturing	Department for Business, Innovation and Skills
Tim Minshall	Deputy Head	Cambridge University Institute for Manufacturing
Rob Scudamore	Associate Director	TWI
Rob Sharman	Global Head of Additive Manufacturing	GKN Aerospace
Robin Wilson	Lead Technologist	InnovateUK
David Wimpenny	Chief Technologist – Component Technology	Manufacturing Technology Centre

The group was initially chaired by Chris Carr, a senior civil servant from the Department for Business, Innovation and Skills (BIS) with responsibility for manufacturing policy. At that time, representatives of BIS made it clear that the intent was not to produce a government strategy for AM, but rather for this Steering Group to coordinate the development of an industry-led strategy for the UK with the support of the Government. In order to clearly signal this intent, a selection of leading figures from UK manufacturing industry (as shown in Table) to write a joint letter to the then Minister of State for Skills and Enterprise, Matthew Hancock, highlighting the importance of the adoption of AM technologies for the future competitiveness of the UK. This then led to a meeting of the signatories of this letter with the Minister, where endorsement was gained for the development of a strategy, and a statement that its recommendations would be 'welcomed' by the government. Following this meeting, and to signal the importance of the strategy development process being industry-led, Neil Mantle (Head of Additive Manufacturing at Rolls-Royce plc) took over from Chris Carr as Chair of the Steering Group, with Rob Scudamore (TWI)[2] as Deputy Chair. Amanda Allison (Additive Manufacturing Project Leader at TWI) provided project management support, a role later taken on by James Logan from the Manufacturing Technology Centre (MTC)[3].

[2] https://www.twi-global.com/
[3] http://www.the-mtc.org/

Table 2

Name	Role	Organisation
Mark Buswell	Head of Advanced Manufacturing Technologies	GlaxoSmithKline Research & Development Limited
Sebastian Conran	Director	Sebastian Conran Asssociates
Sir James Dyson	Chairman	Dyson Limited
Mark Elborne	President and CEO	GE UK and Ireland
David S Holmes	Director of MAI Manufacturing Function & Investment & Infrastructure Services	BAE Systems (Operations) Limited
Paul Howells	R&D Packaging Vice President	Unilever
Sir David R McMurtry	Chairman and CEO	Renishaw plc
Hamid G Mughal	Director of Global Manufacturing	Rolls-Royce plc
Rob Sharman	Global Head of Additive Manufacturing	GKN Aerospace Services Ltd
Michael Straughan	Member of Board, Manufacturing	Bentley Motors Ltd

4.2. Initial evidence gathering (early 2015 – end 2015)

The positioning paper [27] provided a broad view of the opportunities and challenges relating to the adoption of AM gathered from a view of secondary data sources. The Steering Group recognised the need for input from a wider range of sources representing the views of UK organisations either involved in the supply or the use of these technologies. The Steering Group also recognised the importance of signalling to the UK AM community that the strategy development process was to be as open as possible, with strong engagement of private and public stakeholders throughout the process. The decision was made to run a two-stage process for gathering evidence; firstly a series of multi-organisation workshops were to be run followed by the implementation of on-line open call for input. Resources for the research activities was provided via the University of Nottingham and the University of Cambridge as these activities fell within the remit of existing research council and charity funded research projects being run at these two universities.

4.2.1. Workshops

Three workshops were held in the period March-June 2015 and the on-line submission of evidence ran from April-June 2015. Details of the three workshops held are given in Table 3. The original

intent had been to run a single workshop as part of the evidence gathering process, with attendees specifically targeted by Steering Group members to ensure a balanced coverage of sectors and organisations. However, the level of interest combined with capacity constraints at the venue led to a second open event being held later that month. Analysis of attendees revealed an absence of attendees related to motorsport, so an event specifically for that community was arranged.

Table 3

Date	**10th March 2015**	**25th March 2015**	**25th June 2015**
Venue	Manufacturing Technology Centre, Coventry, UK	University of Nottingham, UK	Manufacturing Technology Centre, Coventry, UK
Participation	Open	Open	Motorsport related
Attendees	111	32	20

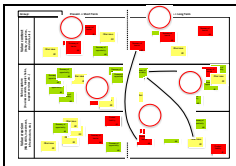
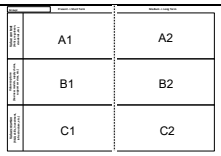
A common process[4] was used at all three events. Attendees were organised into groups (aligned to their primary sector affiliations) and given the task of discussing their individual perceptions of opportunities, barriers and other issues relating to the adoption of AM in the UK. These perceptions were then noted on colour-specific Post-It notes (Green = opportunity; Red/pink = barrier; Yellow = unspecified) and placed onto a mapping template. To preserve anonymity but allow for the organisers to link individual contributions to attendees' organisation and sector during the evidence analysis process, contributors wrote their delegate number on each Post-It added to the map. There was then an opportunity to highlight linkages between the issues. Members of each group then voted on the top 3-5 issues on their map that they felt were of particular relevance for further analysis, and highlighted these with arrows.

All attendees were then given a chance to review a full set of the maps, and to provide comments on any arising issues. After the event, input from all of the 848 Post-Its was captured in a spreadsheet, and this was made publicly available via the UK AM National Strategy website[5]. A summary of the process is illustrated in Table 4.

[4] The process drew upon standard processes used for the development of Technology Roadmaps (www.ifm.eng.cam.ac.uk/roadmapping/).

[5] www.amnationalstrategy.uk

Table 4

				
Explanation	**Discussion**	**Mapping**	**Sharing / linking**	**Coding**

4.2.2. On-line call for evidence

An open call for evidence was promoted via the workshops, email lists and social media. A website was developed and used as a portal for electronic submissions of evidence, as well as the sharing of updates relating to the strategy development process[6]. The website allowed submissions to be made in a variety of formats, ranging from unconstrained (e.g. existing reports, sources of data, or any comments could be emailed directly to the research team) to constrained (e.g. an on-line form requesting responses to specific questions derived in part from issues raised at the workshops). The constrained submissions could be made either using a Qualtrics[7] survey tool, or via a Microsoft Word form.

Submissions could be made on behalf of individuals, organisations or communities.

When the Call for Evidence was closed, 56 fully completed responses from key stakeholder organisations were received, along with numerous reports, papers, presentations and other sources of data.

4.2.3. Analysis

In total, through the workshops and on-line submission, input was captured from individuals representing 143 organisations. In addition, throughout the process, members of the Steering Group were sent numerous reports, presentations, and other sources of secondary data that were reviewed and catalogued. All submissions were reviewed manually to identify common themes, and then electronically analysed using text coding of themes via MAXQDA[8] to identify the frequency of appearance of these themes in the primary and secondary data.

[6] http://www.amnationalstrategy.uk/
[7] http://www.qualtrics.com/
[8] http://www.maxqda.com/

4.2.4. Outputs of initial engagement

Table draws upon the analysis described above and shows the rank order of the most frequently noted 'Top Challenges' chosen by members of each of the 13 groups at the three workshops. These results were used to structure the analysis of the contributions captured from the 848 individual inputs from the workshops and the 56 detailed on-line submissions.

Table 5

Ranking of top issues	Comments
1. Materials	Materials availability / protection, consistency, standardisation / certification, characterisation.
2. Standards	Mainly for materials, but also more generally (e.g. products made using AM processes).
3. Cost	Realistic estimate of costs compared to scale of opportunity to allow for viable business case, cost of testing / development.
4. Education / Skills	A broad range of issues including general level of awareness of AM, what skills will be required / availability of skilled people.
5. Design / Software	Issues of design and software were bundled together by groups – design guidelines, modelling, design opportunities.
6. IP	Balancing need to collaborate with IP concerns, IP and material availability.
7. Measurement	Particularly technology for in-process inspection.
8. Scale-up	Not clear whether this relates to increase in physical volume and/or numbers produced.

Results of the in-depth analysis are shown in **Error! Reference source not found.**, revealing a different rank ordering of perceived barriers and more details on the issues of concern.

Table 6

Theme	Summary of common perceived barriers
1. Materials & processes	Understanding properties in different processes / machines / applications, QA, costs, availability (IP constraints, independent suppliers), use of mixed materials, recyclability, biocompatibility.
2. Design	Need for guides and education programmes on design for AM – better understanding of design for AM constraints, availability of AM-skilled designers, security of design data.
3. Skills & Education	Lack of appropriate skills (design, production, materials, testing) preventing adoption, up-skilling current workforce vs. training of next generation, education of consumers, awareness in schools.
4. Costs, Investment & Financing	Funding to increase awareness and reduce risk of adoption (testing, scale-up, machine purchase) – especially for SMEs, understanding of full costs (including post-processing, testing), cost of materials.
5. Standards & Regulation	Perceived or actual lack of standards – all sectors / sector specific (especially aero / health / motorsport), for processes / materials / software / products / applications.
6. Measurement, Inspection & Testing	Need data libraries, standards for tests (general and sector specific), materials/ in-process / final part, tests for higher volumes, non-destructive testing, QA through lock-in c.f. open access to data.
7. IP & Protection	Balancing need for openness to share knowledge with need for commercial protection to capture value from investments, enforcement of IP rights.

Contributors to the workshops and on-line call for evidence were also asked to consider the main opportunities for AM in the UK. A very wide range of opportunities was noted with much less commonality than for the barriers. The opportunities highlighted were either very generic (e.g. 'customisation potential', 'design freedom') or very sector or company specific (e.g. 'obsolescence management for custom car spares', 'custom sportswear'). However, there were some broad opportunity areas noted several times in various guises. These included: (1) the potential for the UK to set standards in a number of AM-related areas; (2) the role that AM adoption could play in changing perceptions of STEM careers and up-skilling of the workforce; (3) the opportunities that could be realised as a result of the way in which AM builds on existing UK strengths in materials research, design and related technologies (e.g. lasers and inkjet); and (4) the fact the UK already has many of the individual elements that could be connected to form a strong platform for value capture from AM adoption.

The initial analysis of the results of the evidence gathering process revealed strong commonality of concerns around perceived barriers to the adoption of AM in the UK. Top among these are issues relating to materials, design, skills and education, costs and investment, standards and regulations, measurement and testing, and IP and protection. The perceived opportunities for the UK cover a very wide range, but stakeholders believed that the UK had the potential to build on strong existing capabilities [28], and that there was an urgent need to ensure that such opportunities were not missed. These two key conclusions provide a basis for the development of the strategy.

4.3. Developing the Strategy - Part I (January – September 2016)

Following the workshops and data analysis the Steering Group – which by this time had moved to having weekly conference calls and face-to-face meetings as needed – focused on actions required to (i) develop the strategy and (ii) plan the associated implementation activities. To support both of these activities, the Steering Group decided to establish:

1. A single-point-of-contact website to help disseminate information on AM;
2. A Special Interest Group (SIG) to provide a network for sharing AM developments;
3. A trade association to represent the needs of companies interested in AM; and
4. Thematic working groups to drill down into the issues shown in Table 6.

During this period it was agreed that increased industrial representation was important and invited two additional industrialists onto the steering group (Clive Martell from Renishaw and Simon Locke from Dyson). During this period, it also became clear that the involvement of the High Value

Manufacturing Catapult[9] (part of the network of UK centres "*[..] designed to transform the UK's capability for innovation in specific areas and help drive future economic growth*" [29]) would be critical, particularly in terms of ensuring that the implementation activities recommended were aligned with existing and planned manufacturing-related support activities. To address this concern, Ian Collier (Director of Operations at High Value Manufacturing Catapult) was invited to join the Steering Group. The membership of the Steering Group at this stage is shown in Table .

Table 7

Name	Role (at outset of strategy process)	Organisation
Neil Mantle (Chair)	Additive Layer Manufacturing Executive	Rolls-Royce
Rob Scudamore (Deputy Chair)	Associate Director	TWI
Ian Collier	Director of Operations	High Value Manufacturing Catapult
Phill Dickens	Professor of Manufacturing Technology	University of Nottingham
Charles Featherston	Research Associate	Cambridge University Centre for Science, Technology and Innovation Policy
Brian Greenwood	Deputy Head (Materials & Engineering)	Department for Business, Innovation and Skills
Louise Jones	Knowledge Transfer Manager	InnovateUK, KTN
Simon Locke	Head of Manufacturing Engineering	Dyson
James Logan	UK CR&D Funding Manager	Manufacturing Technology Centre
Clive Martell	Head of Global Additive Manufacturing	Renishaw
Tim Minshall	Deputy Head	Cambridge University Institute for Manufacturing
Clare Porter	Head of Manufacturing	Department for Business, Energy & Industrial Strategy
Rob Sharman	Global Head of Additive Manufacturing	GKN Aerospace
Robin Wilson	Lead Technologist	InnovateUK
David Wimpenny	Chief Technologist – Component Technology	Manufacturing Technology Centre

4.3.1. Establishing a single-point-of-contact

The single-point-of-contact was intended to curate a publicly available database of AM documents and events, and act as central contact point both for firms interested in adopting AM, and for those interested in engaging with the development of the national strategy. This led to protracted discussions regarding conflicts of interest, the need to maintain neutrality, and avoidance of any preferential promotion of services. The Steering Group decided that the National Centre for Net Shape and Additive Manufacturing[10] (based at the Manufacturing Technology Centre[11]) should

[9] https://hvm.catapult.org.uk/

[10] Later re-named the UK National Centre for Additive Manufacturing.

organise and manage a website to of key relevant events, resources, and people[12] under the banner of 'Additive Manufacturing UK' (see **Error! Reference source not found.**). The old website that had been used for data capture during phase 2 was kept as an archive of resources relating to the development of the strategy (see **Error! Reference source not found.**).

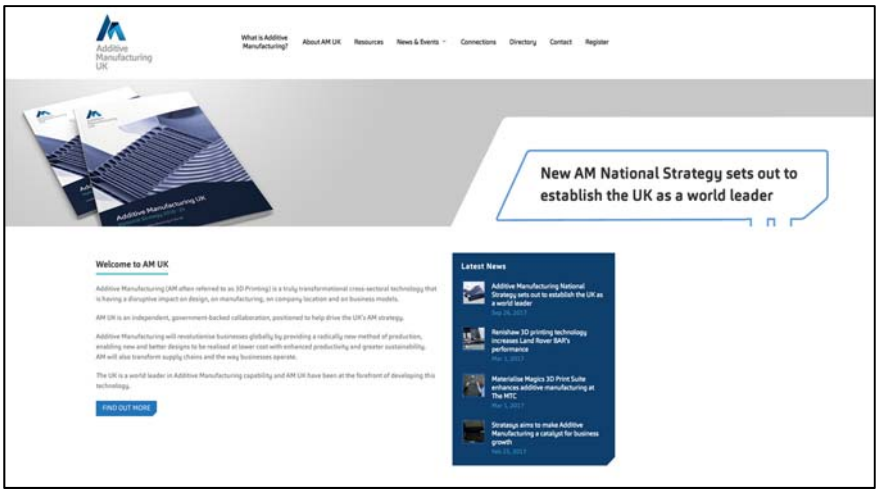


Figure 3: The AM-UK branded website

[11] http://www.the-mtc.org/, one of the seven centres grouped together as the High Value Manufacturing Catapult (https://hvm.catapult.org.uk).

[12] http://am-uk.org/

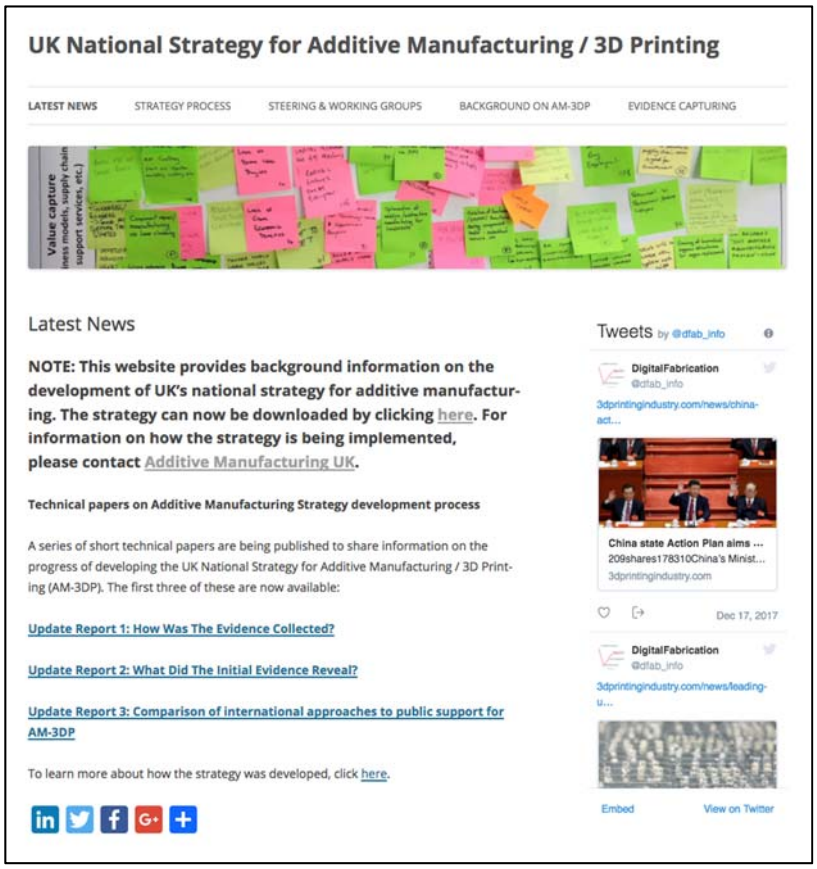


Figure 4: The AM strategy development website

4.3.2. Establishing an AM Special Interest Group

To help connect the UK AM community, a proposal was submitted to InnovateUK's Knowledge Transfer Network (KTN)[13] programme to set up an Additive Manufacturing Special Interest Group. This was approved and launched in 2016[14], under the management of Louise Jones (InnovateUK KTN Manager), who also joined the Steering Group.

4.3.3. Establishing an additive manufacturing trade association

The Steering Group discussed at length the possible need for a trade association for UK AM companies. Issues discussed included potential benefits, options for its organisational structure, and membership protocols (i.e. open to UK firms only, or open to all firms). Other trade associations – such as the UK's Association of Industrial Laser Users[15] – were used as examples. During this period

[13] https://www.ktn-uk.co.uk/

[14] https://www.ktn-uk.co.uk/interests/additive-manufacturing

[15] http://www.ailu.org.uk/

the Steering Group was approached by, or made aware of, existing trade associations whose management believed that their association or network already represented (some part of) the UK AM community. These interactions revealed that the case for the establishment of a new AM-specific trade association was not sufficiently compelling at that time. It was decided that if the case was to change the AM-SIG could potentially evolve in the future to take on the role of an AM trade association.

4.3.4. Establishing Thematic Working Group Activities

The Steering Group established seven thematic working groups to explore in-depth each top-level barrier identified during the data-gathering phase. The Steering Group identified and discussed potential chairs for each of these Working Groups, and the final selection is shown in Table 8.

Table 8

Theme	**Chair / Co-chairs**
1. Materials & processes	Rob Scudamore (TWI) and Clive Martell (Renishaw)
2. Design	Ben Griffin (InnovateUK)
3. Skills & Education	Frank Cooper (Birmingham City University)
4. Costs, Investment & Financing	Richard Hill (NatWest)
5. Standards & Regulation	Alex Price (BSI)
6. Measurement, Inspection & Testing	Peter Woolliams (NPL)
7. IP & Protection	Susan Reiblein (HP)

Membership of the Thematic Working Groups was drawn from individuals from a broad range of organisations within the UK AM community, some of whom were invited, some of whom had volunteered. They included representatives from a broad range of companies (from manufacturing to banking, from legal services to design services, from large to small), government departments, government agencies, universities, and consultancies.

The task given to each Working Group was to drill down into the issues identified during the data gathering, to characterise the challenges, and to design (or identify) mechanisms by which they could be addressed. Following a workshop that brought together the proposed Working Group leads and nascent membership, each Working Group was given the freedom to address the task as they saw fit, and used a variety of mechanisms. These mechanisms included reviewing and analysing existing data, capturing new data through workshops and expert meetings, and sharing results by publishing case studies and running dissemination events. The Steering Group brought the Working

Group chairs together from time to time to encourage cross-fertilisation of approaches and results. Through this process, the Working Groups identified 61 challenges and recommended 75 activities that could be used to overcome them. These provided a key input to the development of strategy and implementation plan.

4.3.5. Developing a 'Platform Document'

In June 2016, the Steering Group began to draft a document that positioned AM as a key technology for the UK economy, summarised the outputs of the initial data collection exercises, and presented an overview the implementation activities required to overcome the barriers to the wider adoption of AM in the UK. The initial intention had been for this document to be 'The Strategy' and for it to be published at the end of the summer 2016 to influence decisions on government funding programmes that could be announced in the government's autumn economic statement. However, two factors led the Steering Group to reconsider this plan:

- **Results of the June 2016 Brexit referendum:** the decision for the UK to leave the European Union led to extremely high levels of uncertainty throughout the UK economy and government. As such, it became clear that decisions on funding and support for the type of AM implementation programmes being proposed by the Steering Group and Working Groups would not receive serious attention at this time.

- **Development of a UK Industrial Strategy:** the UK government had begun to talk about publishing a UK Industrial Strategy in 2017, with a 'green paper' consultation document to be published in early 2017, and the actual strategy released later in 2017. This strategy would define where substantial funding would be targeted on areas of perceived need in the UK economy.

These factors presented the Steering Group with a dilemma: on the one hand, the uncertainty caused by the Brexit decision pointed to a need to delay publication of the strategy; on the other, the announcement of the intent to develop a UK Industrial Strategy pointed to the need for a clear strategy for AM that could explicitly feed-in to the Industrial Strategy. The Steering Group decided that it was important to maintain momentum but, given the uncertainties, not publish the final strategy at this time. The compromise decision was reached to release an interim document (a 'Platform for Engagement' [30]) that would provide an update on progress, present the emerging recommendations, but highlight the need for further refinement and targeting of implementation activities. This document was published in September 2016 at a public event for the AM community

held at the Department of Business, Energy and Industrial Strategy in London. A key part of the agenda for this launch event was the opportunity for the Thematic Working Group leaders to present the results of their activities to the wider AM community. This was felt to be particularly important in order to avoid the risk of disengagement of these volunteers that could result from the decision to delay publication of the final strategy. The decision to publish the final strategy document in 2017 was also announced at this time.

4.4. Developing the Strategy – Part 2 (October 2016 – July 2017)

Following the publication of the Platform for Engagement document, the Steering Group met to review its approach within the changing economic and policy context. The Steering Group identified two additional activities that needed to be undertaken: First, there was a need to refine and collate the Thematic Working Group challenges and recommended actions. A sub-group of the Steering Group took on the responsibility of engaging with the Working Groups to discuss connections and overlaps between the various challenges and recommended actions. This process was finalised in a joint Steering Group and Working Groups workshop held in March 2017 where a joint set of challenges and recommendations was agreed.

Second, to address concerns that sector-specific issues were not receiving sufficient attention, three members of the Steering Group volunteered to engage with the various UK industry leadership councils (e.g., the Automotive Leadership Council, the Construction Leadership Council, and the Association of British Healthcare Industries). While representatives of some of these groups responded positively, engagement with them to the point where they were able to contribute significantly to the strategy development at this stage of the process proved to be difficult.

During this period three issues emerged that impacted on the final stages of the AM strategy development process:

1. **Industrial Strategy Challenge Fund:** As anticipated, the government announced in its autumn economic statement the formation of a 'Challenge Fund' (which became known as the Industrial Strategy Challenge Fund (ISCF)), which was designed to fund industry-research collaborations aimed at addressing specific industrial challenges related to a range of technologies [31].

2. **Clarity of the process of developing the Industrial Strategy:** The UK Government began to seek inputs for the development of its Industrial Strategy. Significant time in the Steering

Group meetings, and between meetings, was devoted to trying to understand how the Industrial Strategy was evolving, how AM could fit within this strategy, and how the AM Steering Group could most effectively engage with this process. The decision as made for the Steering Group to make a joint input to the consultation, the results of which were published in January 2017 [32].

3. **Industrial Digitalisation Review:** Within the report summarising the results of the consultation on the Industrial Strategy [32], it was also announced that the CEO of Siemens UK (Jürgen Maier) would be leading a review of industrial digitalisation (published in 2017 as the 'Made Smarter: Review' [9]. This was recognised to be of particular significance for the work of the AM National Strategy Steering Group as AM could be regarded as one of the key technologies for industrial digitalisation. However, particular concern was noted at how AM might be 'subsumed' within the broader debate on industrial digitalisation, and that the case for support for AM could be become less clear.

These issues led to a dividing of activities for members of the Steering Group, with some efforts being targeted on preparing a bid for the Industrial Strategy Challenge Fund, and some on the completion and publication of the AM strategy document. Substantial effort was also put into developing and maintaining strong links with the team responsible for the Industrial Digitalisation Review.

The Steering Group also underwent a number of changes. First, the chair, Neil Mantle, stepped down and Paul Unwin, ex-industrialist with substantial AM experience was invited to take his place. Second, Professor Ken Young, Head of the National Centre for Additive Manufacturing, was invited to co-chair the Steering Group. Third, personnel changes and shifting resources in the civil service and agencies meant that the two representatives from the Department of Business, Energy, and Industrial Strategy and Innovate UK no longer attended Steering Group meetings.

4.4.1. Development of the Industrial Strategy Challenge Fund (ISCF) proposal

Following the announcement of the Government's ISCF programme, a sub-group of the Steering Group began preparing a bid to ISCF designed to fund some of the implementation activities proposed by the Thematic Working Groups. The nature of the scope of the ISCF call meant that some of the activities that had been proposed but the Working Groups (e.g. an AM skills delivery programme) would not be eligible for funding via this route. The sub-group synthesised the challenges and identified 12 streams of activity that required funding; designed a governance

structure that would identify, allocate resources to, and monitor smaller projects; and identified matched funding that individual firms would be investing into AM that could be used to support the bid. The outputs of this exercise were used to finalise the bid to the ISCF. The 12 streams of activity in the final proposal – which requested funding of UK£169m – were:

1. Coordinated AM research programme
2. Catalyst (Research and Innovation) Programme
3. Programme of Contract R&D calls tailored to strategic priorities
4. Phase 2 Investment in National Centre for Additive Manufacturing
5. Extension to Catapult "Reach" programme targeting AM for SMEs
6. UK Supply Chain Reinstatement Programme (via High Value Manufacturing Catapult)
7. Rapid Prototyping and Tooling Tactical Programme for Tier 3-4 SMEs
8. Accelerated UK-wide awareness programme (through KTN SIG)
9. Definition of AM skills requirements
10. Support development of an Expert UK AM User Group
11. Establish & run National Help/ Contact Point for firms new to AM
12. Programme and Project Management (aligned with AM Steering Group)

Through the period of the ISCF proposal preparation and bid reviewing process, the Steering Group noted a lack of clarity in many of their engagements with government agencies. This was a result of the complex policy environment created by the interplay between the development of the UK Industrial Strategy, the Industrial Digitalisation Review, the planned multiple waves of ISCF funding, the multiple bids being prepared for ISCF funding that were in some ways complementary and other ways conflicting with the AM ISCF proposal, all of which was happening in a time of high pressure for many policymakers as they focused on preparation for the UK's exit from the EU.

An outline proposal was submitted in May 2017. Over the summer of 2017, a series of 'Challenge Workshops' and 'Deep Dives' to identify and quantify the most compelling areas for ISCF support were run by the UK government. One result of these activities was, after some discussion, the merging of the AM ISCF proposal with a separate proposal that had been submitted on the topic of industrial digitalisation. This merged proposal was not successful in being awarded funding in the second round of the ISCF programme.

4.4.2. Development and publication of the final Strategy Document

By the end of 2016, there was a clear view from the Steering Group that a final version of the strategy document should be released as soon as possible. The group believed that a failure to do so could result in a loss of credibility and goodwill among the AM community that had been brought together over this three-year period. The task of drafting the final version of the UK AM National Strategy was taken on by a sub-group of the Steering Group in January 2017. This sub-group drew upon all the evidence captured to date, and the process of analysis and synthesis undergone to produce the Platform for Engagement document and the ISCF bid document. The final document was structured around an articulation of the business case for UK firms to be involved in AM; the barriers that prevent this potential value from AM from being created and captured, and clear recommendations for how each of these barriers can be addressed, linked to an integrated implementation plan. The decision was made to have forewords written by the chair of InnovateUK (Phil Smith) and the chair of the Industrial Digitalisation Review (Jürgen Maier), with explicit endorsement of the strategy by the group of leading industrialists who had been involved in the strategy development process from the outset.

The final strategy [33] was published in September 2017, with a launch event held at the TCT Show (a leading industrially-focused conference on AM) in Birmingham.

5. Conclusions

5.1.1. Outputs and outcomes of the strategy development process

The three-year process aimed at the development of a strategy delivered a range of outputs, beyond the publication of the platform, positioning and strategy documents. These included the formation of new 'institutions' and resources:

- **Formation of 'Additive Manufacturing UK':** The Steering Group effectively became 'Additive Manufacturing UK' in the eyes of key AM stakeholders. This 'brand' became the *de facto* single point of contact for the UK AM community, supported by and based at the HVMC's Manufacturing Technology Centre.
- **Formation of the InnovateUK KTN AM Special Interest Group:** The formation of the InnovateUK KTN Special Interest Group focused on AM was an important signal that industry wanted a community of practice to allow them to share experiences and access resources.

- **Formation of Thematic Working Groups:** During the period of the strategy development process, several of the Working Groups went beyond their intended initial role and continued to operate quasi autonomously as convenors of those interested in specific AM-related themes.
- **Formation of a considerable evidence base:** During the strategy development process data was collected on the opportunities (including potential applications), barriers, catalysts, and challenges to the further development and adoption of AM technologies. This has been an important resource in shaping the establishment of the AM-SIG, the ISCF proposal, and priorities for collaborative projects within the community. This evidence will continue to be useful in future activities.

These outputs resulted in the following outcomes:

- **Engagement of the UK AM community**: Prior to the launch of the strategy development process, the UK AM community as such did not really exist. The community was engaged through a number of mechanisms including the formation of steering and working groups; participation in events; and input to the evidence gathering activities.
- **Informed community of deep thematic knowledge**: Several of the Working Groups went beyond their intended initial goal of gathering, collating and submitting evidence for the development of the strategy and have developed their own programmes of activities. One example of this can be seen in the work relating to AM skills development.
- **Informed community**: Aside from the core function of guiding and coordinating the development of the national strategy, the Steering Group meetings proved to be a valuable platform for the sharing of emerging policy, industry and academic issues directly or indirectly related to AM. One example of this was the maintaining of links with the Industrial Digitalisation Review as several Steering Group members were involved in aspects of this.
- **Development of an AM Industrial Strategy Challenge Fund (ISCF) proposal**: The announcement of the call for large-scale bids for funding to address major 'challenges' presented a significant opportunity but also major difficulties – particularly given the very short timescales available for preparation. However, the Steering Group was able to draw upon resources and knowledge brought together via the strategy development process to respond in a timely manner (even though its initial bid was unsuccessful).
- **Delivery of and engagement with AM events:** Throughout the AM strategy development process, a series of events were organised with specific objectives (e.g. capture data, share

results, engage stakeholders, etc.). In addition, members of the Steering Groups and Thematic Working Groups also ensured that responded positively wherever feasible to requests to speak at AM-related events in the UK and internationally, to raise awareness and build engagement.

- **Consistent and well-evidenced input to external activities:** The evidence relating to AM that has been collected helped inform input into external activities and reviews. The material was made available to InnovateUK and other funding bodies. Furthermore, it informed the AM-related material in the *Made Smarter: Review* and the UK Government's Industrial Strategy.

5.1.2. Observations on the process

Though the case study presented here presents a unique situation, several observations can be made that might assist those involved in developing similar public technology strategies.

- **Context**: There were two contextual issues that made the development of this strategy particularly difficult. First, there are those issues relating to the technology itself. AM is not a single technology, but rather multiple technologies (combining different materials and processes) many of which are at different stages of technical maturity, with multiple possible application areas, each of which are at different levels of commercial maturity. This resulted in real problems in communicating to those unfamiliar with the technology, e.g. explaining to non-specialist stakeholders the difference between the terms AM and 3D printing, and the difference between the use of AM for prototyping versus tooling versus final part production. Second, the development of this strategy happened during a period of extreme political and economic change. Not only did the process coincide with changes of government and leadership that reflected very different approaches to the role of the public sector in supporting industry, but this was all happening in the context of the UK's exit from the EU. The result of this was a near constant state of uncertainty and lack of clarity on key issues. Clearly these were beyond the control of anyone involved in the process, but there was an underestimation of how these issues would impact upon the required style and content of communications between stakeholders and on the management of expectations.
- **Clarity of aims:** As many of those involved in this process did not have significant direct experience of developing a public technology strategy, this led to some confusion of both purpose and process. Even quite late in the process, there were discussions on the nature of strategy, with conflicting views repeatedly coming to the fore. This was not helped by the changing policy context, which led to changing guidance on the core purpose of the

document (i.e. whether it should simply be a document that demonstrates that the UK has a strong AM community with significant industry support and a clear vision for the future, or a direct 'ask' for public money to address a perceived market failure).

- **Design of approach**: Early in the process, lessons were drawn from the development of other public technology strategies, in particular, the UK National Composite Strategy [10]. Key people involved in that strategy were invited to present to the Steering Group on their approach. This provided valuable insight, but the context within which that strategy had been developed, the characteristics of the core technology, and the differing levels of resource available, meant that this approach could not be replicated exactly but did provide valuable insight to the design of the approach for the AM strategy. A specific issue for the AM strategy related to the use of Thematic Working Groups. While these groups provided valuable theme specific input to the strategy, several of the Working Group leads reported that they did not feel that they had sufficient guidance at all stages of the process on the desired processes and outcomes.
- **Resources and support:** For much of the period described in this case study, there was little direct funding provided to support these core strategy development activities. While members of the Steering Group and Working Groups volunteered their time[16], there was a need to have core management resource available to ensure effective administration of the process. At different stages government departments and the High Value Manufacture Catapult provided funding for project management, though at several stages when funding was not forthcoming, volunteers from organisations represented on the Steering Group filled this role. The importance of core funding was key to ensure that momentum was not lost, key documents and data were managed, and the process was kept on-track the light of the very uncertain and changing context.
- **People involved:** It was crucial to involve the appropriate people in the Steering Group and in the Thematic Working Groups. The Steering Group required not only people with technical knowledge, but also those with an understanding of the operational, human resources, financial, strategic benefits, and issues related to AM in firms. It also required an understanding of the regulatory environment and experience of the public and collective strategy development process. The thematic leads were also chosen carefully because they had to operate between the thematic groups' work and the Steering Group. Those in the

[16] Some of the academic members of the Steering Group (Phill Dickens and Tim Minshall) were able to link their involvement in the strategy development activities to EPSRC-funded research activities.

Thematic Working Groups also needed a detailed understanding of the theme to which they were to contribute.

- **Engagement, expectations and momentum:** Throughout the development of the strategy, there were varying expectations within the Steering Group and across the broader community of stakeholders on the purpose and impact of the strategy. Attempting to understand, align and manage expectations resulting from this diversity of views caused delays to the delivery of the strategy. This was in tension with the sense of urgency created by the desire to deliver the strategy while there was interest and support from the AM community that had been brought together through the workshops and awareness raising activities. It as also noted that there were challenges in getting consistent engagement with relevant sector groups.

5.1.3. Suggestions for further work

This paper has presented a description and reflection on a single case study of the development of a public technology strategy for AM in the UK. The lessons described above highlight a clear need for experience from the running of similar strategy activities to be codified and made available to those involved in such activities in the future. Further research could review the increasing number of published public technology strategies and extract the key learnings on process and outcomes in differing contexts to help ensure that the lessons from these complex activities are not lost. Research could also explore how the characteristics of the core technology (or technologies) and different governance structures affect the approach taken.

Conflicts of interests

Both authors were members of the UK AM National Strategy Steering Group, and members of the organisations (the University of Cambridge Institute for Manufacturing and University of Cambridge Centre for Science, Technology and Innovation Policy) that undertook much of the data gathering and analysis that was used to underpin the formulation of the strategy documents.

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