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Additive Manufacturing Innovations by UK Organisations

A review of patents and literature published between 2006 and 2015

Jane List and Frank Tietze

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Capturing the value from the digital fabrication revolution

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Executive summary

This study examines the state of additive manufacturing (AM) innovation within UK-owned organisations that have published AM-related patents or other literature between 2006 and 2015 inclusive. Other organisations who play a vital role in the AM innovation system in the UK may not appear in this report if they have neither produced publications (which are included in secondary databases) nor had any patents published in that period.

Whilst previous studies have considered this topic by reviewing either patents or scientific/technical literature, this report looks at both, with the aim of producing a comprehensive overview of AM activities, specifically by UK organisations. Also in contrast to previous studies, we have aggregated the data at the organisational level. Our aim was to identify active players in AM, including universities, through their publications[1]. In total, our study found seven types of organisation namely company, university, research institute, governmental organisation, hospital, charity and museum. All organisations have been geographically located according to their operational activities (rather than their registered address) in order to analyse where AM activities are actually taking place in the UK. The study analysed the organisations in terms of 13 economic sectors, 14 AM categories (these define AM technology or other AM activity as described in the patents and papers) and three supply chain positions.

In total this research identified 121 UK organisations actively patenting and/or publishing in the field of additive manufacturing between 2006 and 2015. These organisations filed 142 patent families and published 362 papers between 2006 and 2015, making an average of 1.2 patents and 3.0 papers per organisation. Only 16 of the 121 organisations have filed two or more patent families. The top four patentees, with more than ten patent families, were Renishaw, Rolls-Royce, Airbus and BAE Systems. The top five publishing organisations were Loughborough University, University of Manchester, University of the West of England, University of Nottingham and University College London. All of the top 20 publishing organisations are universities. While companies tend to file more patents, universities are more likely to share their work as academic publications. The low patenting figures are in line with the previously-observed, low patenting propensity of UK firms.

The organisations were found to be particularly active in three economic sectors, namely health and pharmaceuticals, aerospace and education. These three sectors are closely aligned with the generic economic profile of the UK. Thirty-four organisations are active in more than one sector. These are all universities, with the exception of Renishaw. Surprisingly, we found very few AM-active organisations associated with the automotive sector. While the UK has organisations involved across the entire supply chain, most of them are active in later positions of the chain, namely industrial users, services and software, and post-processing of components and products. We found that innovations are not always applicable to a single technology, such as Directed Energy Deposition (DED) or Binder Jetting, but are becoming more industry-specific – to be expected in a maturing technology – and also that new materials are being developed specifically for AM. This particularly applies to metal-based AM methods, such as DED and Powder Bed Fusion (POBF). In our dataset we found hardly any indication of Sheet Lamination and very little Material or Binder Jetting-related activities.

In this report we have defined a cluster as a region where organisations of different types conduct activities across several AM technologies and industries, and across different supply chain positions. From our analysis of the geographical spread of organisations, the economic sectors in which they are active and their supply chain positions, we conclude that there are four AM clusters in the UK. Cardiff in Wales forms part of a 'West' cluster together with Bristol and Bath in England. Two other clusters were identified in the Midlands centred around Loughborough, Nottingham and Sheffield, focusing on high technology and manufacturing; and in the north around Liverpool and Manchester. A substantial number of companies are based within Greater London, forming a fourth cluster with a focus on the health and pharmaceutical sector. None of the clusters particularly stand out in terms of size. The number of organisations ranges from 15 (West) to 23 (Midlands). Comparing the clusters in terms of 'innovative productivity' (i.e. publications per organisation) reveals that the West cluster is the most productive one with 5.7 publications per organisation, followed by the Midlands cluster with a productivity of 5.0 publications per organisation. The Greater London cluster has the lowest productivity of 2.5.

[1] 'Publications' here and throughout the report encompasses both patents and acadmic papers.

Foreword

Covering a broad range of technologies, digital fabrication offers the prospect of on-demand, mass personalisation, together with more localised, flexible and sustainable production. These technologies, which include additive manufacturing, have the potential to disrupt the organisation of manufacturing and the ways in which companies – both incumbents and new entrants – create and capture value.

This report is a product of the EPSRC and ESRC-funded project entitled 'Bit by bit: Capturing the value from the digital fabrication revolution' which began in October 2013 and set out to examine the reality and the potential of digital fabrication for the UK economy. This particular patent and publication analysis was commissioned and carried out as a pure, data-analysis exercise to provide an independent picture of the industry.

While there have been previous studies of additive manufacturing (AM) activities, we believe this one is different in two respects. Firstly, this study focuses particularly on AM activities conducted by organisations not only based in the UK but also 'born' in the UK, or at least owned in the UK during the time this study was conducted in spring and summer 2017. Secondly, this study investigates both patents and scientific and technical literature published by UK-owned organisations as part of a combined dataset.

We have done our utmost to ensure this report provides an accurate picture of the UK AM landscape. However, as with all studies, this one is not without shortcomings. We chose to focus on the analysis of organisations we could be sure were working in the field of Additive Manufacturing. Inevitably this approach will have led us to underestimate activity in the field; for instance, we noted under-representation of 'jetting' type AM technologies. We nevertheless hope that the report will complement existing research and thus be helpful to the UK, and possibly the international AM community with a specific interest in what is happening in the UK.

We would like to thank the following people and organisations for assistance in preparation of this report. Tim Minshall commissioned the report as part of the EPSRC and ESRC funded Bit by Bit project. We would like to thank Phil Dickens for reviewing a draft version of the report. Dominik Deradjat has been helpful in confirming the relevancy of retrieved AM patents. Jane Y Ho has assisted with locating AM standards, and by discussing our findings. Alex Maskell has helped with the UK maps, Laura Shipsey with the spreadsheets and Clare Gilmour with editing the report. Clarivate Analytics has provided access to Derwent Innovation which was used for patent searching and for the publications citations analysis. Aistemos has kindly provided access to Cipher which was used for portfolio analysis and global analysis of applicants.

Frank Tietze, Jane List
Cambridge, November 2017

1 Introduction

This study set out to contribute to a better understanding of Additive Manufacturing (AM) activities by UK-based and UK-owned organisations, by analysing patents and scientific and technical literature relating to AM. AM is a term used to describe a number of technologies; some overlap, and some are not closely related at all. AM is often used synonymously with the term 3D printing, although it is becoming more common to use 3D printing to describe decorative objects and consumer items made or printed in small quantities. All AM technologies share at least two common features. In line with ISO/ASTM 5290 2015 these are:

1) AM technologies permit the making of components, products and other items by the accumulation of material, in contrast to traditional manufacture which tends to involve cutting out parts from a large piece of material, as well as joining materials together.

2) The build design for AM is fully created in 3D using computing techniques, such as CAD systems, prior to the build starting.

To provide some context for the UK scene, we compared AM patenting activities in the UK with other leading AM countries between 2006 and 2016. Figure 1 shows the large volume of AM patent filing in China. Almost five times as many patent families were published in China as in the second most active country, the USA. The USA is followed by Japan (JP), Korea (KR) and Germany (DE). The UK (GB) just makes it into the top 10.

A recent report from Imperial College identified the USA, China and Germany as leading AM publishing countries over the last 10 years (Li, J., et al. 2016). Figure 2 (overleaf) compares AM patenting activities in the UK to patenting in these three countries, based on patent families and first (priority) filings from 2006 to 2016. It shows the patenting activity of UK organisations (orange) relative to China (CN), USA (US) and Germany (DE), shown combined in blue. The graph reveals that AM patenting has strongly increased since 2010 across the most active countries, with a substantial step-change from 2014 to 2015. Patenting activity in the UK appears to be increasing at a similar rate to the other three countries, but represents only a relatively small fraction (about 4% in 2016) of the total patent families filed in China, the USA and Germany.

Figure 3 shows organisations with the greatest number of AM patent families, based on data derived from the Cipher platform which uses a proprietary search method grouping AM activities into three categories. The results confirm the dominance of Chinese and US companies, with 19 of the top 20 organisations headquartered in the USA and China. The only European organisation in the top 20 is Siemens (ranked 13), with headquarters in Germany.

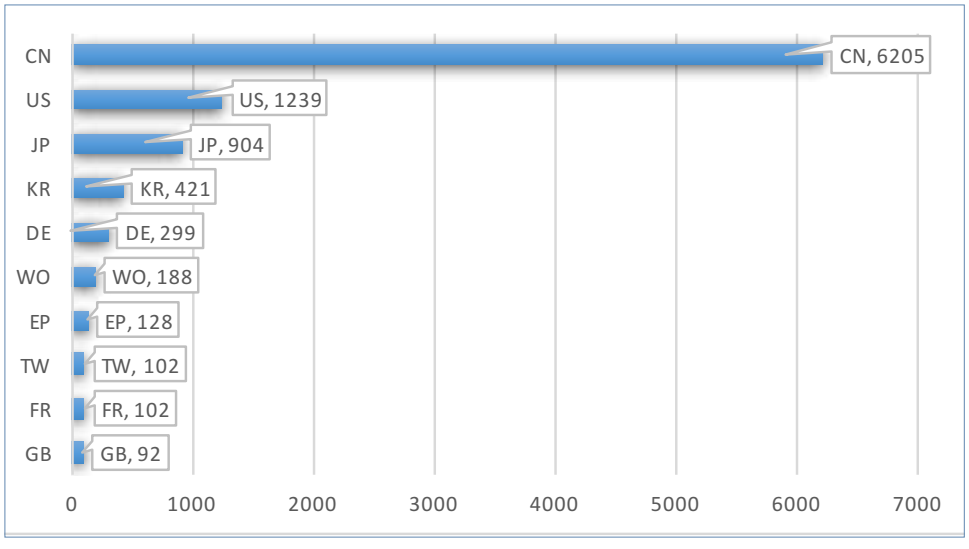

Figure 1: Top 10 countries by AM-related patent families published from 2006-2016 by country of first (priority) filing.

Note: Patent Cooperation Treaty (WO) applications may include applications from any one of 196 authorities, and European Patent Office (EP) applications from 38 countries. However, a review of the UK patents found in this project did not find any companies using the PCT route for the preliminary filing. China (CN) figures include Utility Models as well as Patents of Invention.

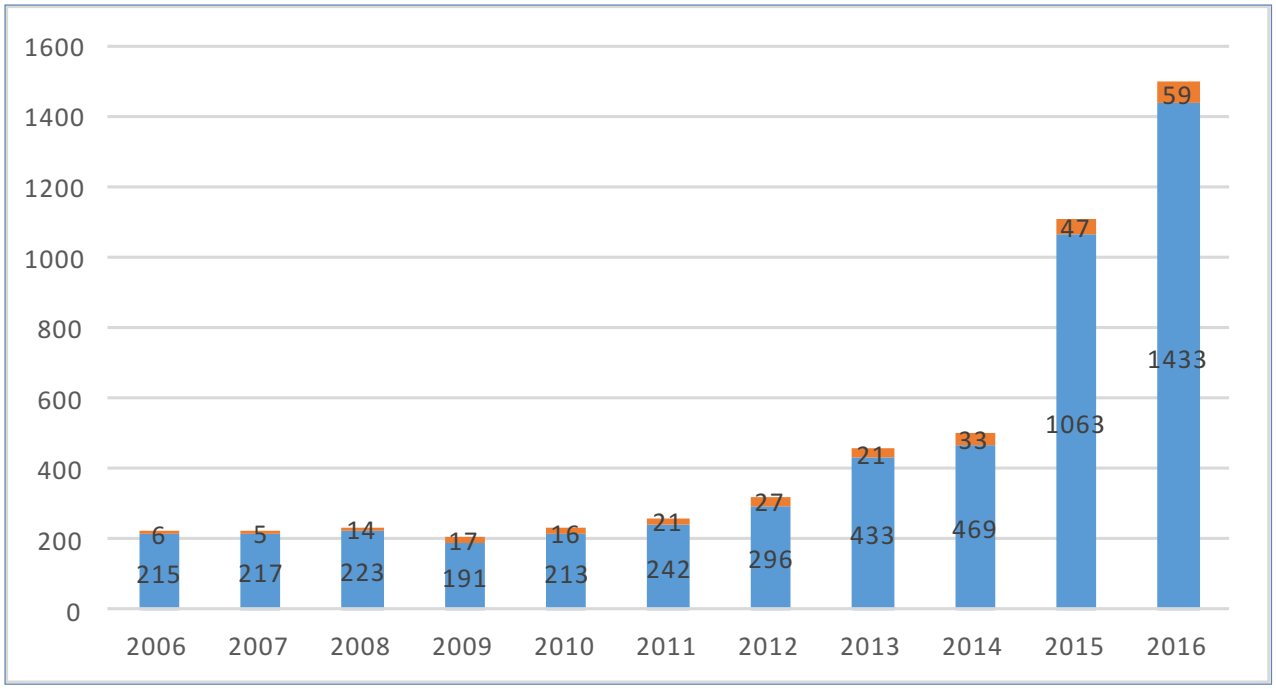

Figure 2: AM patent families with priority countries CN, DE, GB, US, WO, and EP (2006 to 2016). UK patenting is shown in orange; USA, China and Germany are combined in blue.

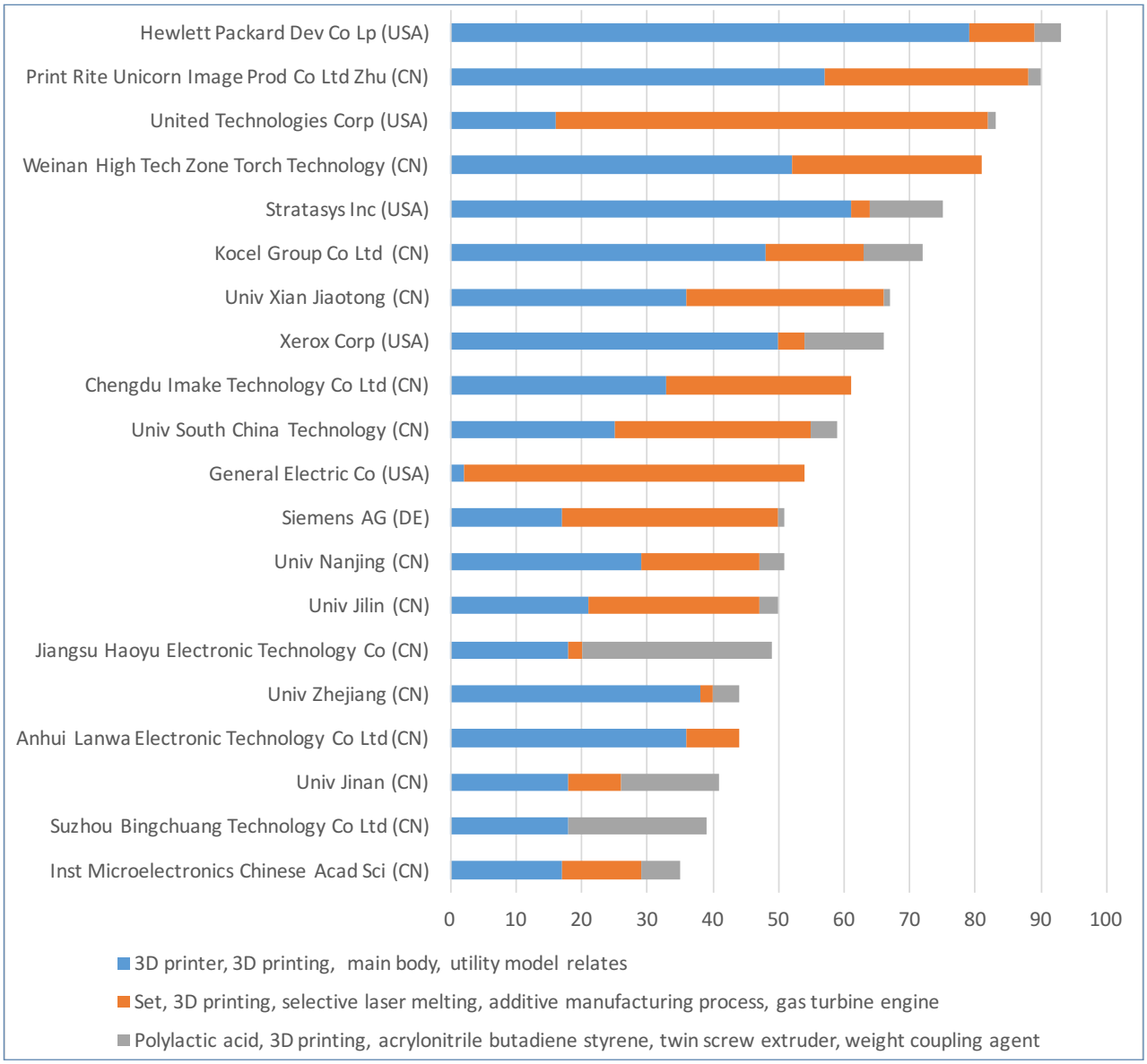

Figure 3: Top 20 AM global patent applicants (source: Cipher)

2 Methodology

Two previous studies of AM patenting were used as the starting point for this project: the UK IPO's 2013 global patenting activity study (UKIPO 2013) and the report by Gridlogics Technologies (2014) which covers global AM patenting activities from 1990 to 2013. A third more recently-published study from Imperial College, that focused solely on university publications and research funding, was identified during the project (Li, Myant and Wu 2016). The Additive Manufacturing UK 2016 report was used as the basis for the technology categorisation of organisations (UK Additive Manufacturing Steering Group 2016).

In contrast to previous studies, which analysed either patenting or publishing activities, this study analysed both patenting and scientific and technical literature in order to measure AM activities in the UK. This approach allowed us to capture a more holistic picture, with both industry (usually biased towards patenting) and academic organisations (usually biased towards publishing) represented; to identify emerging players; and to identify cross-sector collaborations. Figure 4 illustrates the research approach taken.

Figure 4: Flow chart illustrating the dataset creation and analysis process

2.1 Creating the dataset

The dataset was created by reviewing published scientific and technical literature and patents with the primary purpose of identifying UK organisations working in the AM field, to find out what they are doing, where they are based and with whom they are working. UK-based organisations, if owned by a foreign entity, were excluded (e.g. GE or Siemens) in order to focus on AM activities originating from within the UK.

AM-related scientific and technical papers were initially identified using Scopus, Science direct and ProQuest. We used ProQuest data and manual analysis to extract all named authors and institutes (organisations) for each publication. This allowed us to find more details of co-authorship and partnerships. Thomson Innovation was used for the literature citation analyses.

Patent searching was carried out using Clarivate Analytics Derwent World Patent Index on the Derwent Innovation platform[1]. A high-precision, patent search strategy was used to supplement and update the dataset from the UKIPO (2013) report, which was used as the starting point for this study. See Appendix 6.1 for further details on data retrieval.

After the initial data extraction the dataset was manually cleaned. Organisations were removed from the collection if they were found not to be in UK ownership, either at the time of publishing/patenting or subsequently. For example, 22 organisations with overseas parent companies were removed from the patent data. Two further companies, which were acquired by non-UK companies, were also removed from the study. These were Materials Solutions, now owned by Siemens, and Simpleware which was acquired by Synopsys. All patents filed by individual inventors were also checked manually and allocated to an appropriate organisation if evidence was found that the inventors subsequently formed a UK company, otherwise they were removed from the dataset (see Appendix 6.9). Following the search and cleaning process 121 organisations remained and these were included in the analysis. See Appendix 6.10 for the full list of UK AM companies included in this study together with their relevant data.

More information about sources and search strings can be found in Appendix 6.1 and 6.7. Details of patent classifications are provided in Appendix 6.5. Appendix 6.6 provides an overview of the relevant Cooperative Patent Classification (CPC) classes with descriptions of those classes that occurred at least 10 times in the dataset. The classes were mapped against the AM technology categories. This dataset could therefore provide a basis for future work, particularly for those wishing to search for AM processes and materials. For further analysis or replication of our results the dataset, at an aggregated organisational level, is included in Appendix 6.10 and is also available online from the University of Cambridge APOLLO repository: https://doi.org/10.17863/CAM.13916

[1] A number of conferences were identified with additive manufacturing themes, which have resulted in AM papers (Appendix 6.7).

2.2 Overview of the analysis

All analyses were carried out at the organisation level. Each organisation was categorised according to five indicators: geographic location, organisation type, supply chain position, economic sector and additive manufacturing category. A complete list of organisations included in this study, with essential data on each, can be found in Appendix 6.10.

Geographic location

The addresses of all organisations identified from the patent and literature searches were manually checked to enable the cluster analysis to be performed. For the purpose of this analysis we defined a cluster as a region where organisations of different types conduct activities across several AM technologies and industries, and across different positions of the supply chain. Where possible, the geographic locations were mapped by the postcode of the operational headquarters, rather than the registered office. The locations were mapped individually and then grouped into clusters.

Each company was checked to ensure that only UK-owned organisations were included. UK ownership was confirmed using several sources, including the Total Patent database, and by reviewing corporate structures on company websites. Companies with joint, UK-foreign headquarters were included, for example Airbus (with headquarters in the UK and France); and Unilever (UK and the Netherlands). Renishaw acquired MTT Technologies in 2011. MTT publications were included in the Renishaw portfolio.

Organisation type

Each organisation was assessed to determine its legal entity. Seven legal entities were found in the dataset – namely company, university, hospital, research institute, governmental organisation, charity, and museum. Each organisation was classified as one of these legal entity types.

Supply chain position

A three-position breakdown of the AM supply chain was created for this study (Table 1) and each organisation was mapped to a single position of the supply chain.

Position 1	Position 2	Position 3
Machinery manufacturers	Organisations utilising AM processes to manufacture for others	Industrial users
Material research; novel materials specifically for AM	Organisations making improvements to existing technology	Services
Software for AM	AM materials supply	Software
Innovation in basic techniques and complementary equipment e.g. lasers, tools		Post-processing of components/ products

Table 1: Supply chain positions

Economic sectors

We used the categories defined by the UK Additive Manufacturing Steering Group (2016) as our starting point for assigning organisations to economic sectors, adding new sectors as required. Details of the fifteen economic sectors used can be found in Appendix 6.4.

Two new economic sectors were created for the project, these were Energy and ICT. A third sector, MULTI, was used to indicate that companies had activities across the sectors. Some of the descriptions were also extended to clarify the type of activity undertaken – for example advertising was added to Business Services.

Additive manufacturing categories

In order to develop our understanding of the UK's expertise in AM we allocated each of the 121 organisations to one or more AM technology-related categories, based on our reading of the abstracts of the patents and publications. Definitions for each of the 13 categories used in this analysis, with their abbreviations in brackets, are provided in the blue box on the next page. Synonyms used to describe the AM technologies found in the patents and papers, were collected throughout the study and are shown in Appendix 6.2 to assist future researchers in the field.

The thirteen technology categories include six new categories, which we propose in addition to the seven ASTM categories. These are denoted by an asterix (*). A fourteenth category, 'AM', was used when it was not possible, from the information available, to allocate an organisation to a specific category.

Four issues made the categorisation process rather difficult: a) an overlap between technology and material development which can be relevant to more than one AM technique, b) inconsistency in usage of terms, c) emerging, assistive technologies which could apply to more than one activity, d) the term 'additive manufacturing' is often used without sufficient explanation to assign a specific technology. Some organisations were active in more than one AM technology, and in these cases all were taken into account.

Appendix 6.3 provides an overview of the materials used with the AM categories.

AM Categories

1. **Additive Nano Manufacturing (NANO)***: Nano-scale, additive techniques encompasses the following techniques: electro hydrodynamic jet printing, dip-pen lithography, direct laser writing, single particle placement methods such as optical tweezers and electro kinetic nano manipulation.
2. **Directed Energy Deposition (DED)**: Involves feeding powder or wire onto the surface of a part where energy is used to fuse the material.
3. **AM Product (ITEM)***: Any 3D printed object.
4. **Jetting – Binder (BINJ)**: Powdered material is laid out in layers which are joined together by a glue (or binding material) which is deposited on top.
5. **Jetting – Material (MATJ)**: Beads of material are deposited as layers to make objects. Following deposition the material is treated with energy which binds the layers together.
6. **Just In Time (JIT)***: Objects/components are created at the point of use.
7. **Material (MAT)***: Development of new materials specifically for additive manufacturing procedures. May or may not be for a specific technique.
8. **Material Extrusion (ME)**: Materials are dispensed as small beads onto a track or frame and then fused into the desired shape.
9. **Post-processed Feature (POST)***: Post-processed features and innovations during refining after manufacture, for specific products and for identification purposes.
10. **Powder Bed Fusion (POBF)**: The starting material is powder which is treated with an energy source and shaped as needed.
11. **Sheet Lamination (SHLA)**: Layers of material are joined to form an object. Joining can be achieved by several methods including chemical, adhesive and energy.
12. **Software (SOFT)***: Software for the design and processing of AM products and components.
13. **Stereolithography (STLI)**: A liquid resin is cured using energy. The resin is photosensitive and light encourages polymerization to create a solid object.

3 AM UK Landscape

3.1 Patenting and publishing activities

Figure 5 overleaf shows the patents and papers published by all 121 UK-owned organisations from 2006 to 2015. The patenting data reveals a total number of patent families under UK ownership of 142. The graph shows a first wave of activity from 2006 to 2010 with a peak of 13 patent applications in 2008. After 2010 the number of annual patent applications increased further with 30 new patents filed in 2014[1]. The development equals a compound annual growth rate (CAGR) of 22.6%. By contrast, the number of publications in scientific and technical literature has grown each year from four in 2006 to 132 in 2015, reaching a total of 362. This growth is equal to a CAGR of 47.5%. With 121 UK organisations included this indicates an average of 0.2 patents and 1.1 publications per organisation.

The figures show that both patenting and publications relating to AM are continuing to increase. Whether this is because of a genuine increase in activity, or because the phrase additive manufacturing is now more widely used, and AM research is attractive to funding bodies needs to be verified by further research.

Sixteen out of the 121 UK organisations in our dataset (13%) hold at least two patent families, with only four organisations having more than ten in the period from 2006 to 2015 (Figure 6). This implies that a large majority (87%) of UK organisations active in AM do not file patents at all.

[1]Not all patents filed in 2015 were available when the data was collected.

This is in line with observations made in previous studies of patenting activities of UK manufacturing organisations across industries (e.g. Hall 2013). The four major patentees together account for 78 out of 142 patent families, indicating quite a high concentration ratio. These four top performers are Renishaw (28), Rolls-Royce (20), Airbus (18) and BAE Systems (12). Among the 16 organisations with two or more patents there are 12 companies and four universities (Imperial College, University College Cardiff, University of Sheffield and the University of Warwick).

Our dataset included six patents with more than one applicant (Table 2). Among these are two patents filed originally by Fripp Design based in London and Sheffield, of which one is co-owned with the Manchester Metropolitan University and the other with the University of Sheffield. Another of these patents is co-owned by the University of Sheffield together with Loughborough University. Renishaw also co-owns two patents, one with the University of Liverpool and one with another company (Metrology Software products).

Figure 7 reveals the 24 UK organisation that have published three or more AM-related, scientific papers. Note that only universities are represented in this table as no private sector organisations have published three or more papers. Loughborough University is leading the field by a wide margin with 28 publications. It is followed by the University of Manchester (16), and the Universities of West of England and Nottingham (15 each). Ten organisations have published ten or more papers.

Organisation 1	Organisation 2	Publication number	Title	Priority date
Fripp Design	Manchester Metropolitan University	WO2012093257A1	Artificial eyes and manufacture thereof	05.01.2011
Fripp Design	University of Sheffield	WO2012123693A1	Method and system for producing prostheses	15.03.2011
Hybrid Manufacturing	Ex Scintilla	WO2015189600A2	Material processing methods and related apparatus	09.06.2015
Renishaw	University of Liverpool	WO2006131716A2	Process for fabricating a composite	06.06.2005
Renishaw	Metrology Software Products	WO2006024844A2	Machine tool method	01.09.2004
University of Sheffield	Loughborough University	WO2011020912A2	A method, apparatus, computer readable storage medium and computer program for forming an object	21.08.2009

Table 2: Patents with more than one applicant

Figure 5: Annual and cumulative patents (by earliest priority year) and scientific and technical publications (2006-2015)

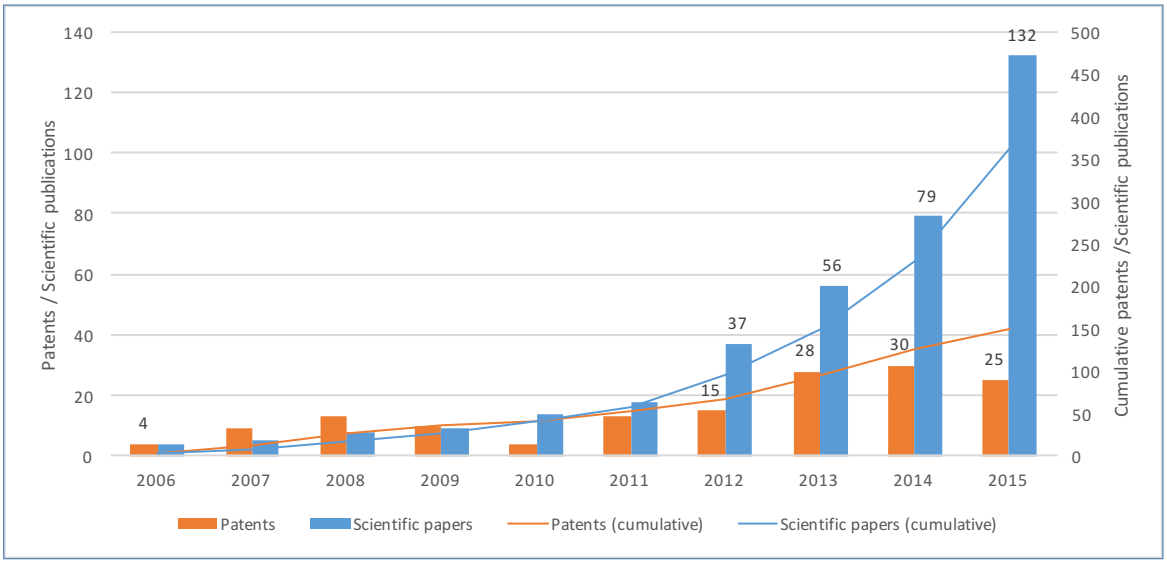

Figure 6: UK organisations with two or more patent families

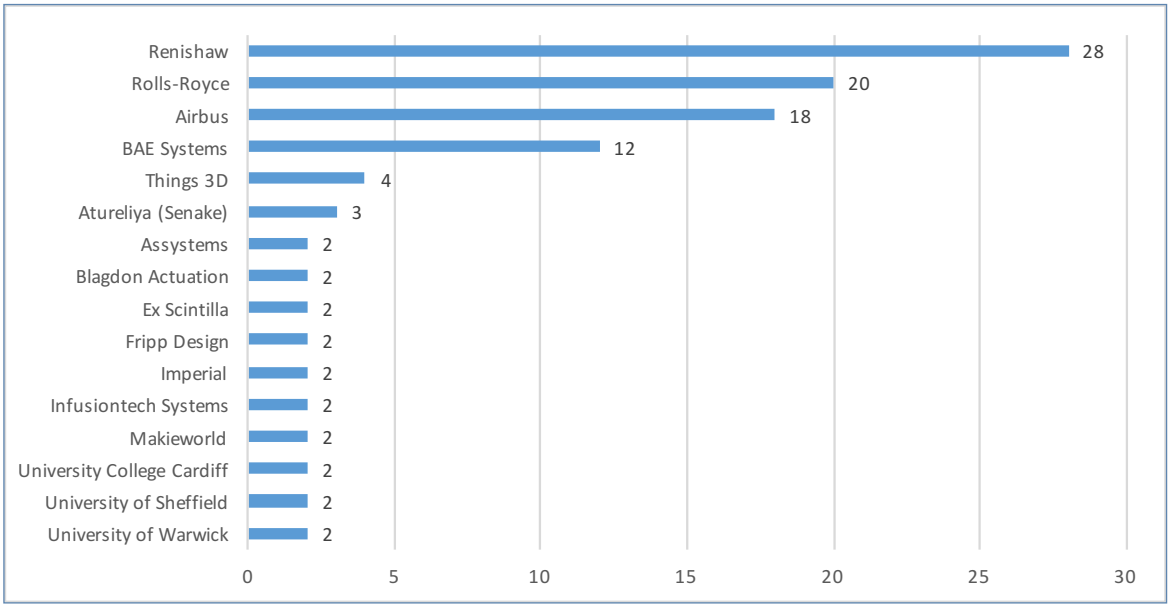

Figure 7: UK organisations with three or more scientific or technical publications

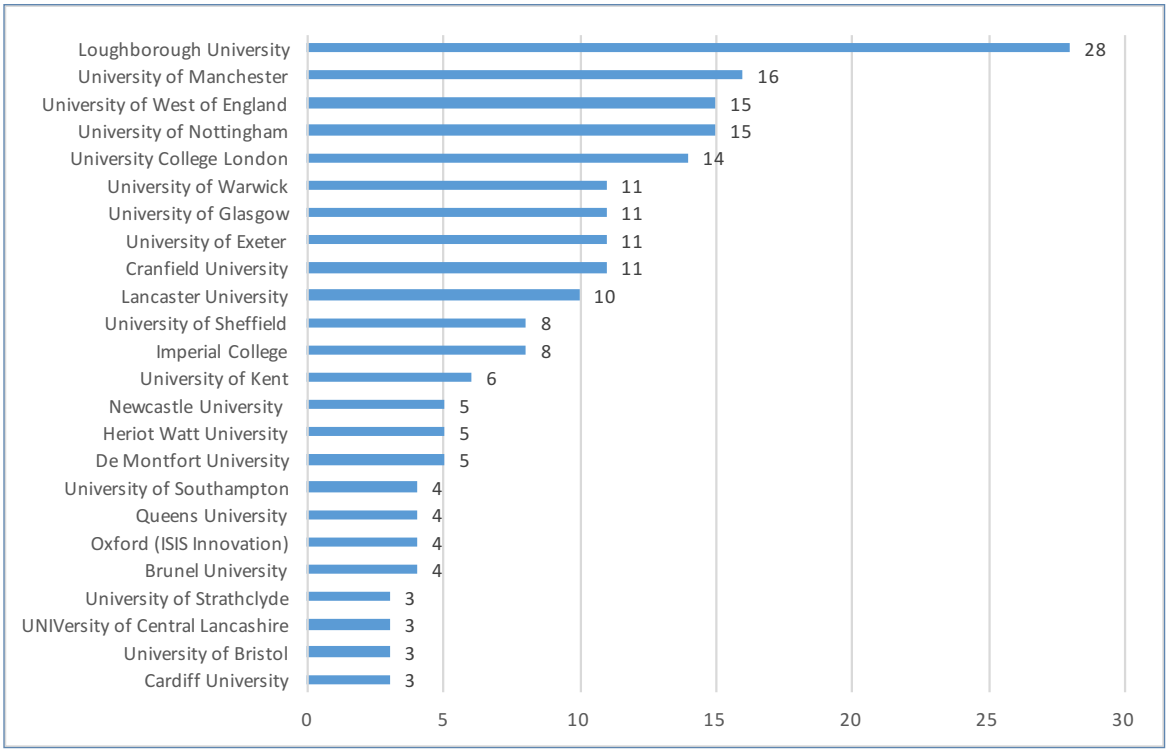

Figure 8 UK organisations holding patents as well as publishing scientific or technical papers

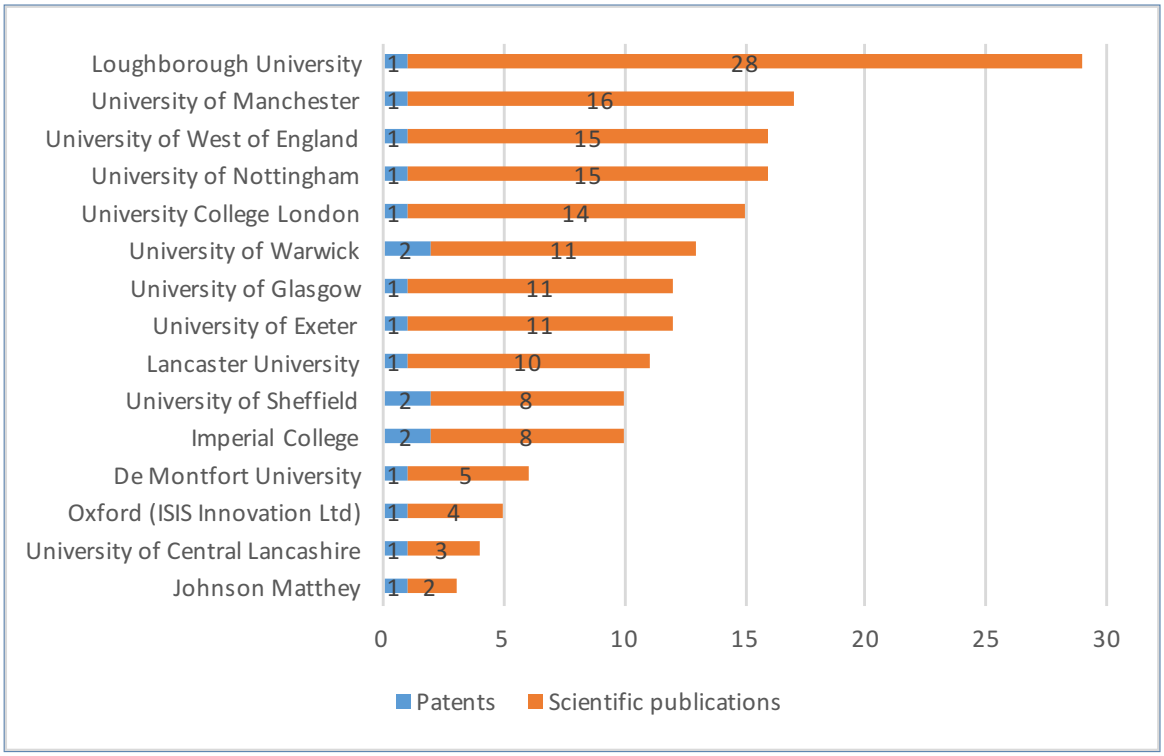

Figure 9: UK organisations with 20 or more citations for their scientific or technical papers

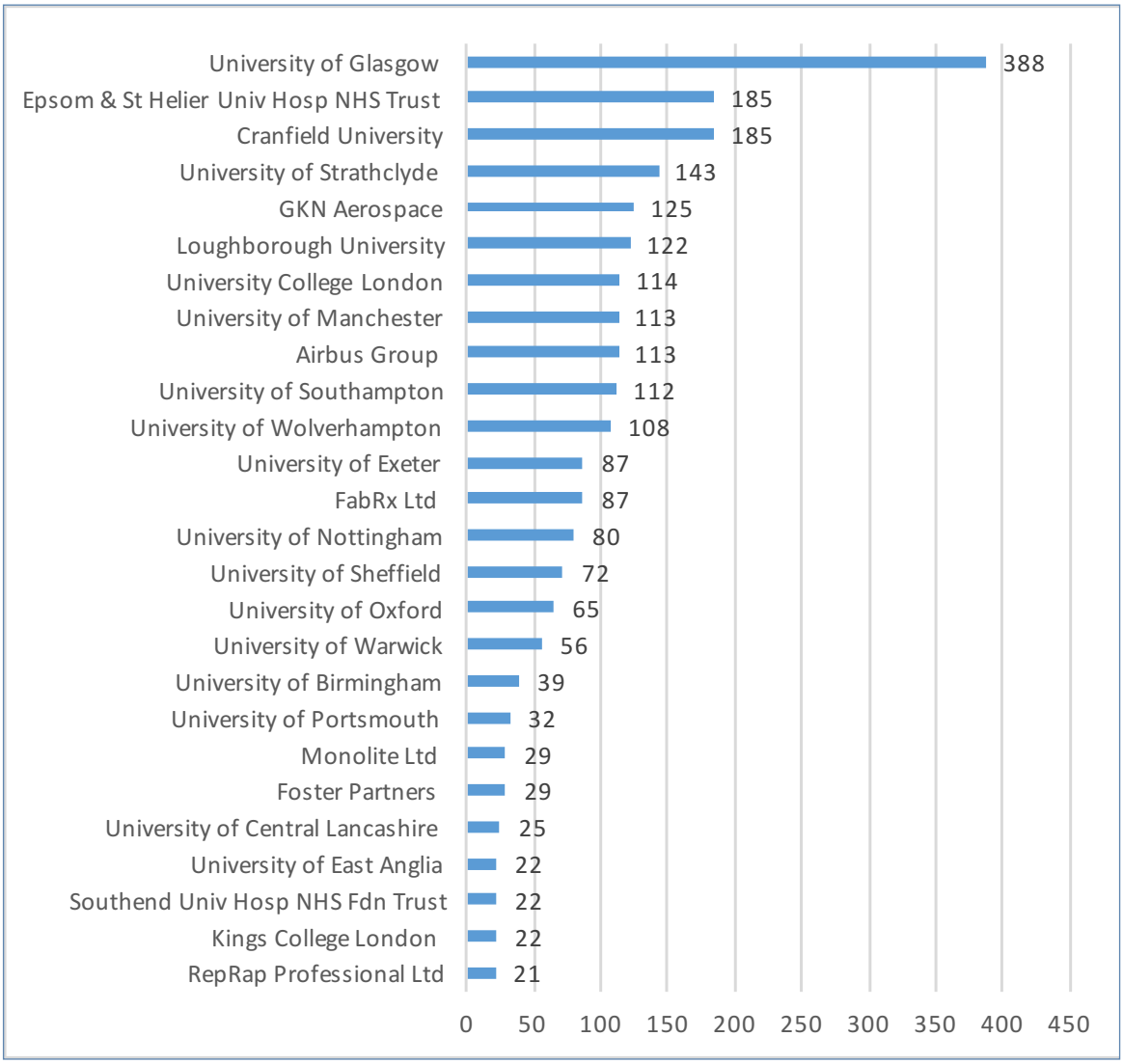

Figure 8 shows the 15 UK organisations that hold at least one patent and have published at least one paper. Loughborough University leads the field with 29 in total, followed by the Universities of Manchester (17) and Nottingham and the West of England (16 each). Eleven of the 15 organisations have ten or more patents/papers each. All but one of the 15 are universities, the exception being Johnson Matthey with two published papers and one patent.

Figure 9 shows UK organisations ranked by the total number of citations received for their AM scientific or technical papers. The list includes 26 organisations with 20 or more citations. The papers of three universities have received more than 150 citations each. The University of Glasgow is leading with 388 citations, followed by Epsom and St Helier University Hospital (185 citations) and Cranfield University (185). While the list is dominated by universities, six companies are included. The top cited company is GKN Aerospace, ranked fifth (with 125 citations), followed by another large corporate, Airbus, ranked ninth (113). The other four companies included in the list are all quite small. FabRx (London) ranked 13th with 87, Monolite (London) ranked 20th (29), Foster Partners (London) ranked 21st (29), and RepRap (Foxham) ranked 26th (21).

3.2 UK organisation types

Figure 10 shows how the 121 organisations are distributed across the seven organisation types. Companies represent the largest category with 50 organisations, amounting to 41% of the total. Universities form the second largest category with 48 active in AM. Together companies and universities make up 80% of all organisations. The third largest category consists of 14 hospitals. There are only 10 organisations in the remaining four categories (see Table 3).

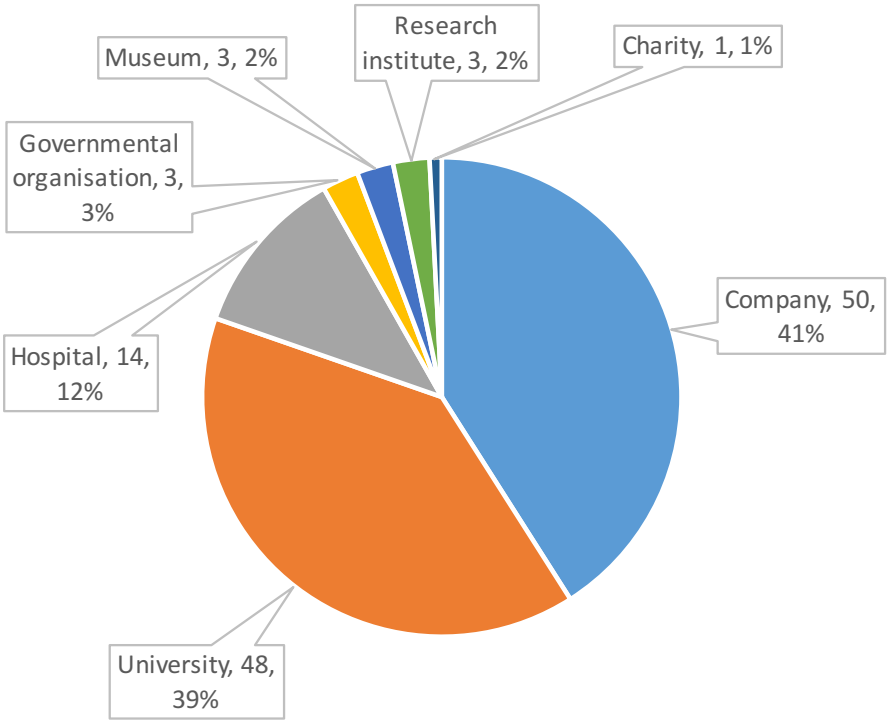

Figure 10: Distribution of AM activities by organisation type

Governmental organisation	Museum	Research institute	Charity
• National Physical Laboratory • NHS England • Advanced Weapons Establishment	• National Museum Wales • Natural History Museum • Newport Museum and Heritage Service	• Institute of Cancer Research • Manufacturing Technology Centre • The Welding Institute (TWI)	• Orthopaedic Research UK

Table 3: Four of the entity types have only 10 organisations in total

Figure 11: Geographical spread by organisational type. Organisations are located according to where they have operational activities and not where they are headquartered.

Figure 11 shows the locations of the 121 AM-active organisations across the UK, with the vast majority in England. In Northern Ireland, Queens University is the only AM-active organisation identified from our research. AM activities in Wales centre around Cardiff, with close links to Bath. About 10 organisations are based in that region, including five universities, four companies and one museum.

In Scotland, there are seven AM-active organisations based in Edinburgh, Glasgow and Dundee. Of these, four are universities (Heriot Watt University, University of Dundee, University of Glasgow and University of Strathclyde), two are hospitals (University of Edinburgh Medical School, Western General Hospital) and one a company (Freeman Technology). With 12 publications the University of Glasgow is the clear leader in Scotland, followed by Heriot Watt University with five. While these Scottish publications relate to different economic sectors, there seems to be a leaning towards the health and pharmaceutical sector.

AM activities in England are more numerous and therefore more complex to decipher. As Figure 11 shows companies, universities and hospitals are spread throughout England. The only charity in our dataset is based in London. Two of the AM-active museums are based in the West and one in London. The three research institutes are based in London, the Midlands and the Eastern region. The three governmental organisations are based in London, the North and the South West. The numerous organisations based in London are distributed across the city.

3.3 Economic sectors and AM activities

Figure 12 (overleaf) shows in which economic sectors the 121 UK organisations in our dataset are active, based on our review of the abstracts of their patents and publications (see Appendix 6.4 for descriptions of the economic sectors). Forty two organisations are active in the health and pharmaceutical sector (27%), followed by aerospace and education both with 11 organisations (7%). Hence, almost 41% of all the organisations are active in these three sectors.

Thirty-four organisations were found to be active in multiple sectors. These are not included in Figure 12. Figure 13 shows the organisations active in multiple sectors with 10 or more publications – a total of nine. These include eight universities and one company. The company (Renishaw) is ranked second, with 28 publications, after Loughborough University with 29.

Figure 14 (see page 18) matches the different organisational types to the economic sectors in which they have published papers or patents. The data shows that companies are active across a number of different sectors, but predominantly in two: health and pharmaceutical, and aerospace. Eleven organisations are active in the aerospace sector with a total of 75 publications. Of these, three companies dominate: Airbus (22 publications), Rolls Royce (20) and BAE Systems (12). Together these three account for 72% of all aerospace-related publications. The University of Leeds is the only university active in this sector according to our data. Of the seven original ASTM categories, we did not find any organisations active in the food and drink or transport sectors.

Universities are mainly active in the health and pharmaceutical and education sectors, but also in construction, consumer goods and, to a limited extent, in aerospace, ICT, defence and general industrial sectors. Research institutes have a few AM activities in the health and pharmaceutical and machinery and equipment sectors. The 14 hospitals in our dataset – each with only one or two publications – are, as would be expected, active in the health and pharmaceutical sector, with a few publications in the education sector. The three museums (National Museum of Wales, Natural History Museum and Newport Museum and Heritage Services) are active only in the education sector. One research institute published in the health and pharmaceutical sector (Institute for Cancer Research) while another, the Manufacturing Technology Centre, published in machinery and equipment. The Welding Institute (TWI) publishes across multiple sectors. Orthopaedic Research UK – the only charity in our dataset – is active

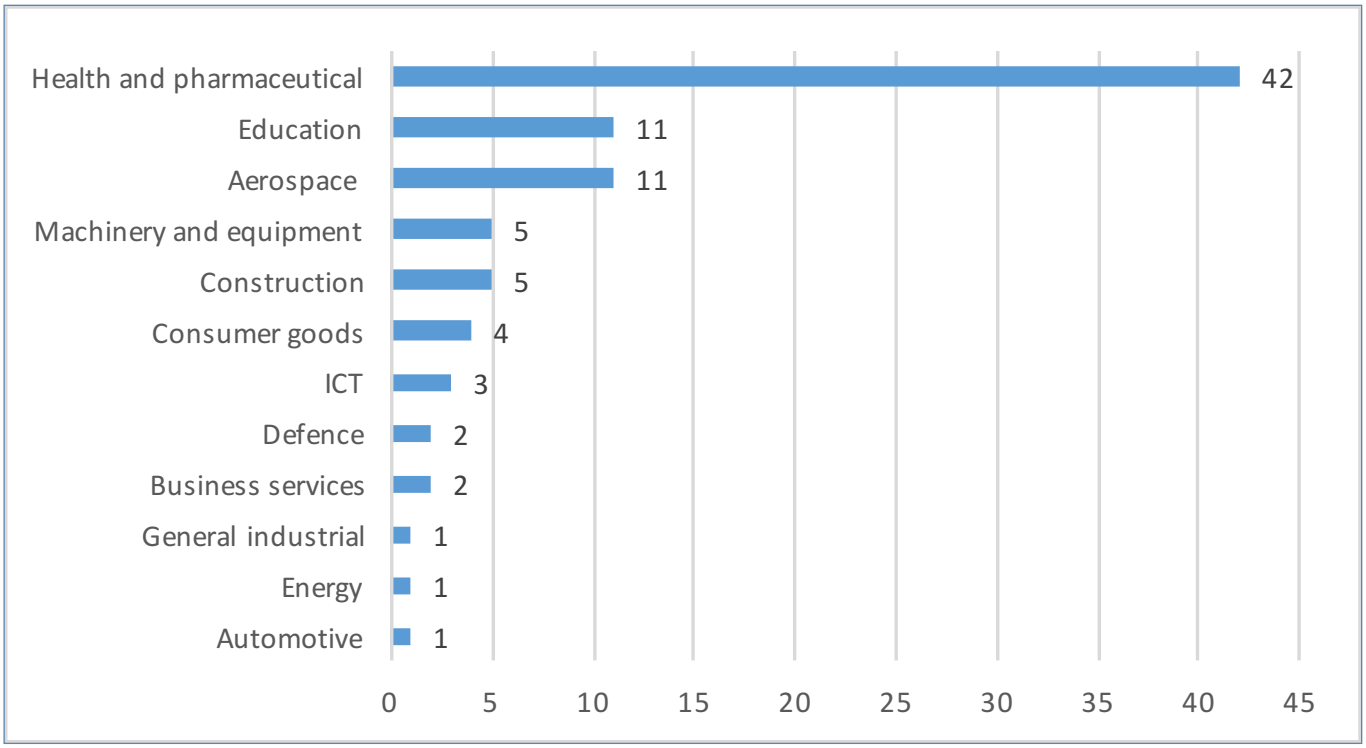

Figure 12: UK organisations active in AM by economic sector

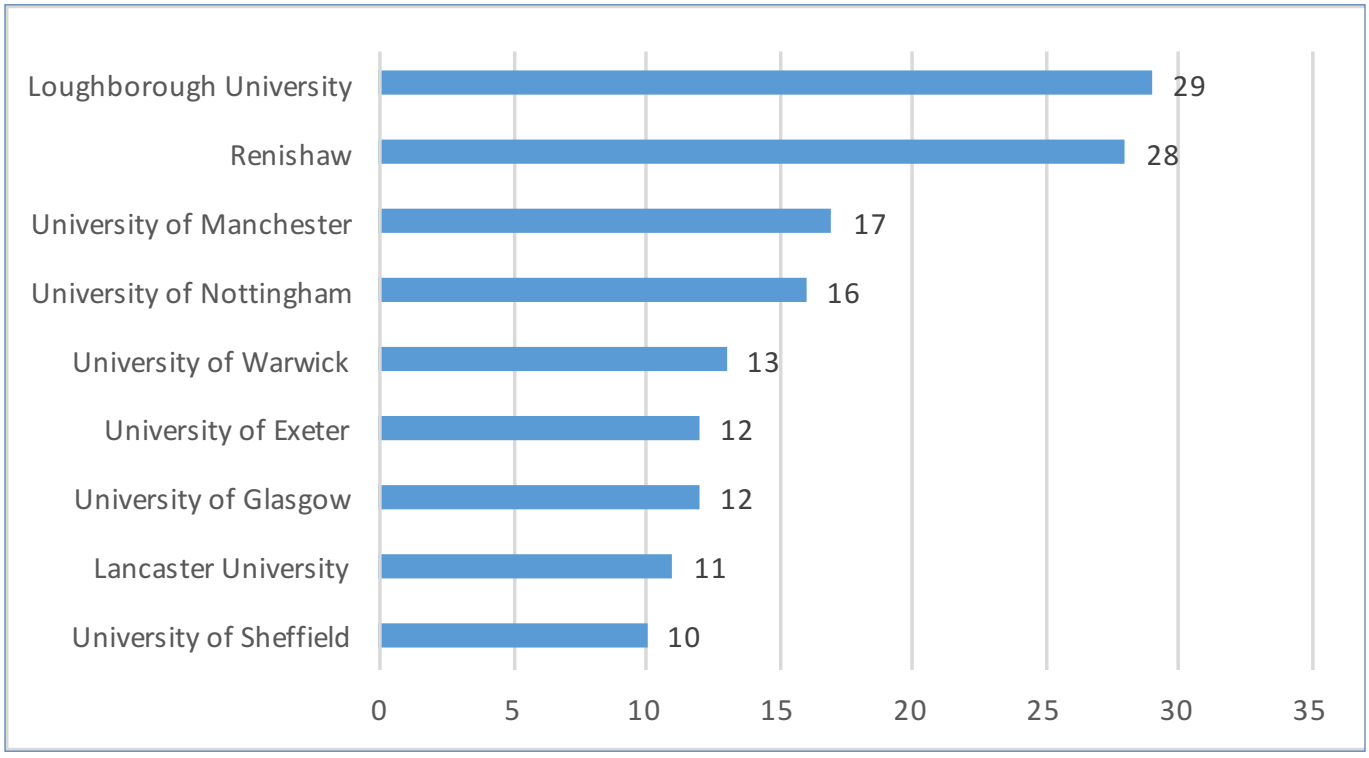

Figure 13: Organisations active in multiple economic sectors with 10 or more publications

in the health and pharmaceutical sector. Three governmental organisations are included in our dataset. The Advanced Weapons Establishment has two publications in the defence sector. NHS England has one publication in the health and pharmaceutical sector. The National Physical Laboratory has one publication in the machinery and equipment sector.

Table 4 (page 19) shows the number of patents by economic sector relating to each AM technology category. No category is dominant across all sectors, however four of the technologies seem to be relatively generic. Material patents were found to be relevant in six sectors. Direct Energy Deposition, Powder Bed Fusion and Software relate to five sectors each. Specific, AM product-related

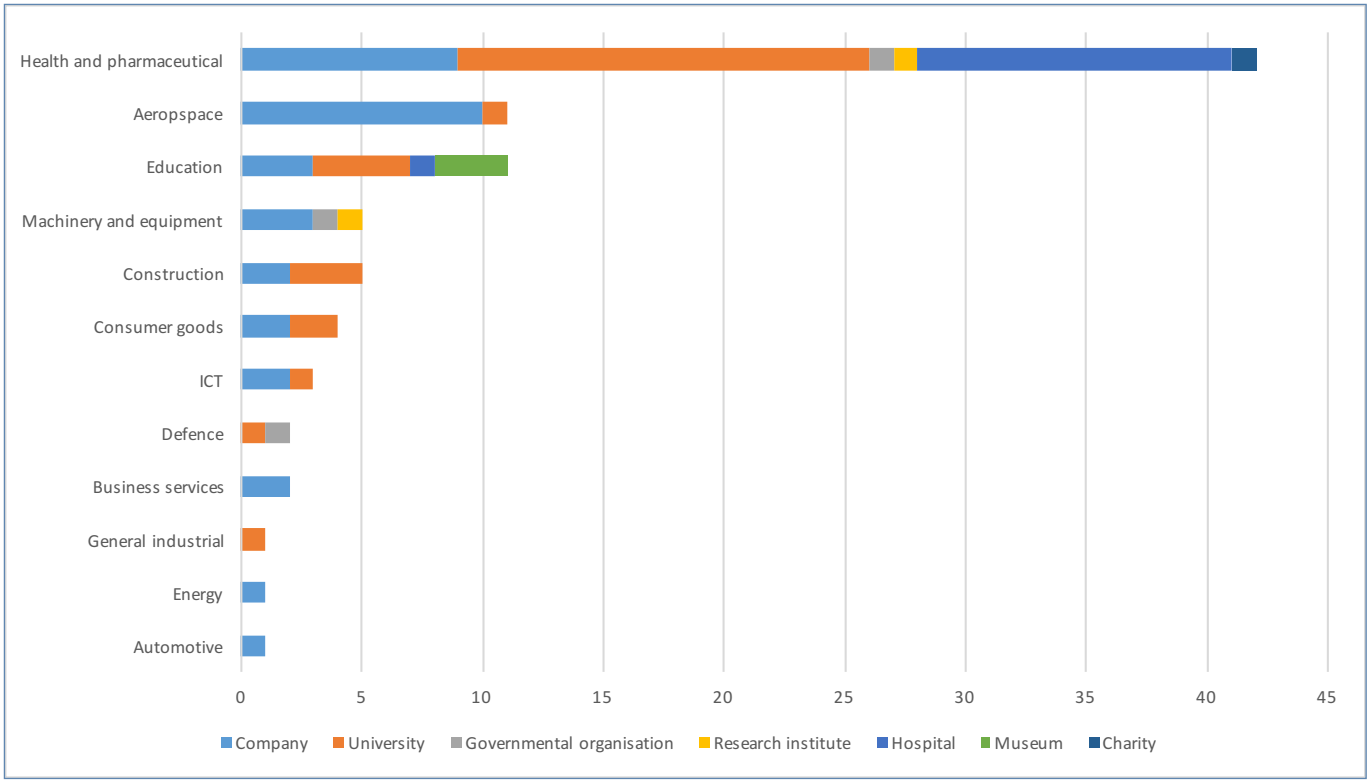

Figure 14: AM activity by organisation type in different economic sectors

patents appear only in relation to the health and pharmaceutical sector while Nano-AM resides only in the education sector. Binder Jetting technology was not found in a specific economic sector, nor was Sheet Lamination.

Figure 15 shows how the AM categories of the 121 organisations are spread across the UK. It does not reveal any particular pattern, except that organisations innovating in software seem to be found more in the southern part of the UK. Most of these are found in Cardiff and Bath, Exeter, Southampton, Reading, Brighton and in Kent.

Figure 16 indicates the geographic spread of organisations by economic sector. It shows that AM activity is taking place in multiple economic sectors across the UK. Organisations with a focus on health and pharmaceuticals are wide-spread – in Belfast, Edinburgh, Blackpool, Liverpool, Leeds, York, Birmingham, Cardiff, Southampton, Norwich, London and in Kent. Out of the 11 organisations that are active in the aerospace sector the major players, with five or more publications, are located in Bristol (Airbus), Derby (Rolls Royce), Farnborough (BAE Systems) and Leeds (University of Leeds). Our dataset only includes one organisation that is active in the automotive sector, a small company named Printed Structures based in Cambridge. One organisation is active in the energy sector (Amec Foster Wheeler, London) and one in the general industry sector (Cranfield University).

3.4 Economic sectors and the supply chain

To analyse AM activities across the supply chain we allocated each organisation to one of three positions in the supply chain (see section 2.2) based on their AM-related activities. Organisations in position one of the chain include those undertaking machinery manufacture, material development, software and technologies complementary to AM, such as lasers and tools. Organisations in position two include those that utilise AM processes to manufacture for others, those that make improvements to existing technologies, and those that supply the material needed for AM. Organisations in position three include industrial users and those providing services and software as well as post-processing of components and products.

Table 5 (page 20) shows the number of organisations at each position of the supply chain across the economic sectors. The largest number of organisations (56) is active in position three, the point at which AM activities have reached the market place. Thirty-three UK organisations are active in position two and 32 in position one, indicating that there is AM activity throughout the supply chain, although position three predominates.

Table 5 indicates that there are six sectors in which UK organisations are active across all three positions of the supply chain (consumer goods, construction, education, health and pharmaceuticals, ICT, machinery and equipment).

AM category / Economic sector	AM unidentified	Jetting - Binder	Direct Energy Deposition	Materials	Material Extrusion	Jetting - Material	Powder Bed Fusion	Stereolithography	AM Product	AM Testing	Nano-AM	Post-processed feature	Software	Just-In-Time	TOTAL
Health & pharmaceutical	14			6	2	7	4		1				7		41
Aerospace & space			2	3	1		7					1			14
Education	6		1								1		2	1	11
Consumer goods				1			2						2		5
Machinery & equipment	4		1												5
Construction				1		2				1					4
Defence	1						1			1			1		4
ICT	2													1	3
Business services												2			2
General industrial			1	1											2
Automotive	1														1
Energy	1														1
Multiple (undefined)	6	1	5	8		5	10	4		1	1	1	9		51
TOTAL	**35**	**1**	**8**	**20**	**3**	**14**	**24**	**4**	**1**	**3**	**2**	**4**	**21**	**2**	

Table 4: Number of patents by economic sector for each AM category

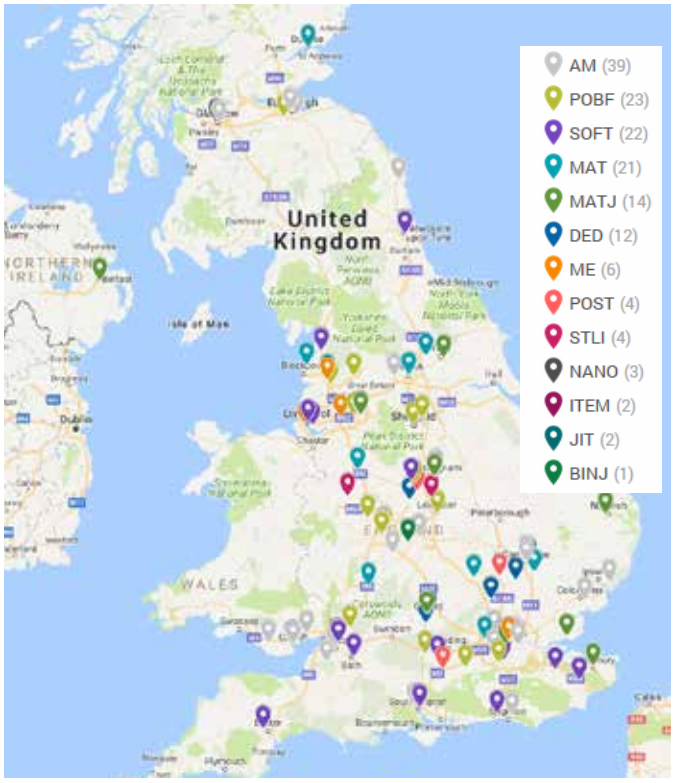

Figure 15: Geographic spread of AM categories. Organisations engaged in multiple AM activities have more than one category indication on the map. Organisations are located according to operational activities rather than registered headquarters.

Figure 16: Geographic spread by economic sector. Again organisations engaged in multiple AM activities have more than one indication on the map. Organisations are located according to operational activities rather than registered headquarters.

Supply chain / Economic sector	Position 1	Position 2	Position 3
Aerospace		4	6
Automotive	1		
Business services			2
Consumer goods	1	2	1
Construction	1	1	3
Defence		1	1
Education	2	1	8
Energy			1
General industrial		1	
Health & pharmaceutical	9	6	27
ICT	1	1	1
Machinery & equipment	2	2	1
Multiple	15	14	5
TOTAL	**32**	**33**	**56**

Table 5: Economic sectors and supply chain positions of active AM organisations (alphabetical order)

These include two of the three economic sectors in which UK organisations are identified as most active – health and pharmaceuticals, and education (see Figure 14 page 18).

The greatest number of organisations is active in the health and pharmaceutical sector, however these are unevenly spread within the supply chain with 27 out of 42 (66%) active in position three. Nine organisations are active in position one and six in position two. In the education sector eight out of 11 organisations are active in position three, with two active in position one (King's College and Cardiff University) and one in position two (Labminds). In the automotive, energy and general industrial sectors the UK has only one active AM organisation in each.

Figure 17 reveals that organisations appear to be quite evenly spread across the UK in terms of their supply chain positions. A fairly large number of organisations active in position one of the supply chain can be found across most regions, with the exception of the area around Cardiff. In addition, relatively few are active in position one in and around London. Organisations active in both the second and third positions of the supply chain seem fairly equally spread.

3.5 AM clusters in the UK

The maps displayed earlier already indicate a certain clustering of organisations in different parts of the UK. While a number of organisations are based in southern Scotland, around Glasgow and Edinburgh, it is difficult to argue that these constitute a cluster. In total these comprise only six organisations.

Figure 17: Geographical spread of organisations by supply chain position.

Figure 18 reveals that across the rest of the UK there are perhaps four clusters. For the purpose of this analysis we define a cluster as a region where organisations of different types conduct activities across several AM technologies and industries, and across different supply chain positions.

The North cluster is based around Manchester, Leeds and Liverpool with 18 organisations. These include eight companies, eight universities, one governmental organisation (NHS England) and the Royal Preston Hospital. Four of these organisations (including the region's major universities) have five or more publications[2]. The University of Manchester and Lancaster University are the only two organisations in this cluster with more than ten publications (Manchester with 17 and Lancaster 11). Only one company in the cluster has more than two publications – Things 3D (4). The University of Liverpool has six publications, the University of Leeds five and the University of Central Lancashire four. Together these seven organisations account for 80% of the cluster's publications. Other companies in the cluster include Assystem, Infustiontech Systems, Amdel Medical, Croft Filters, Invibio, M&I Materials and Position One Creative Services. The organisations in this cluster are quite evenly spread across all three positions of the supply chain. Based on their publications the organisations in

[2] 'Publications' in this section as well as throughout the report refers to patents and/or scientific and technical literature.

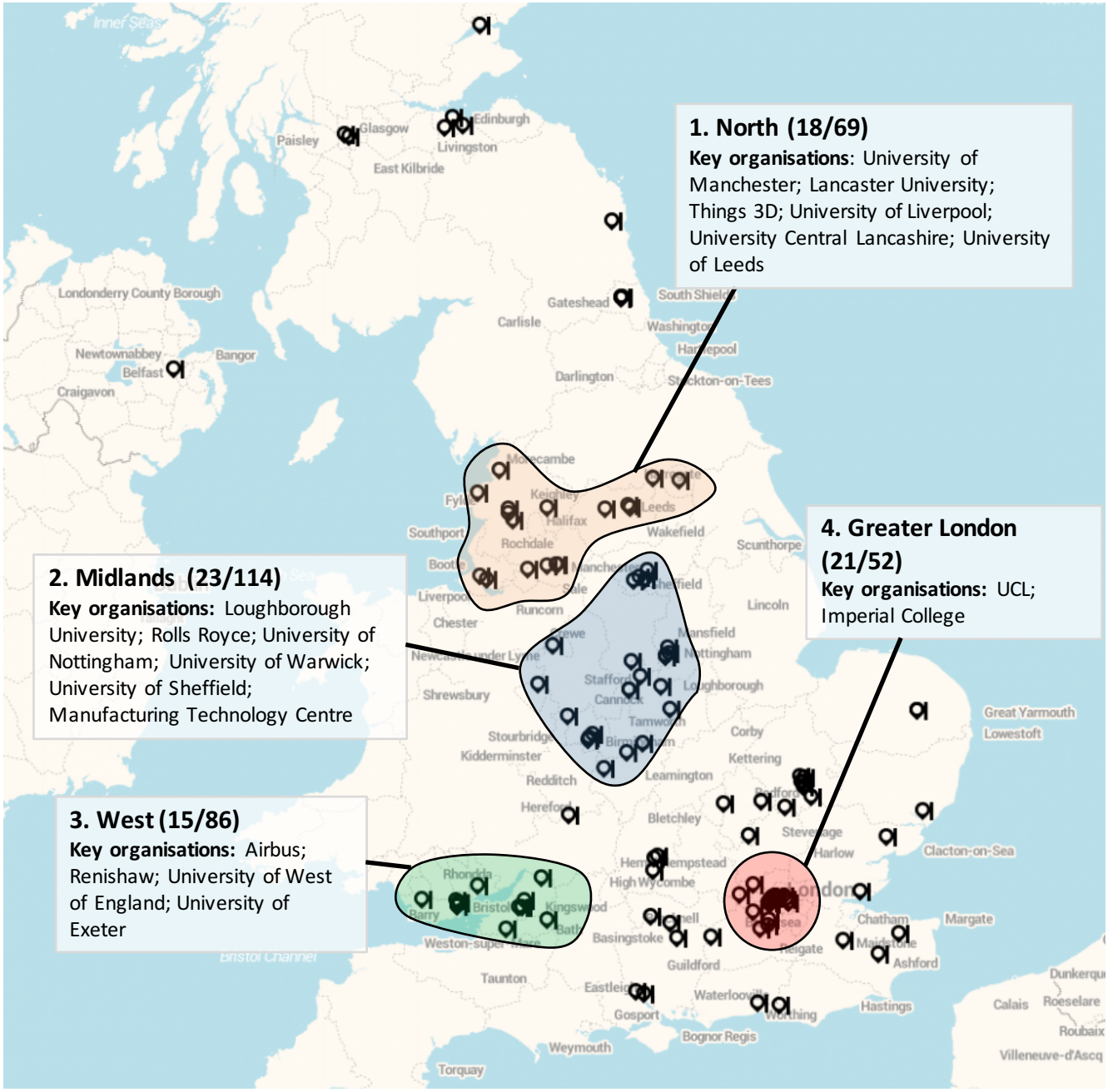

Figure 18: Clusters of UK-owned organisations active in additive manufacturing. For each cluster the first number indicates the number of organisations, the second number indicates the number of publications (patents and scientific or technical papers). Map created using http://mapsdata.co.uk

this North cluster focus specifically on the health and pharmaceutical and aerospace sectors, even though a number of organisations, predominately universities, are active across multiple sectors.

The Midlands cluster includes organisations stretching from Sheffield in the north to just south of Birmingham, with quite a centre of AM activities formed around Nottingham. We identified 23 organisations in this cluster, including 11 companies, 9 universities, two hospitals (Royal Derby and Nottingham University Hospitals NHS Trust) and one research institute (Manufacturing Technology Centre). The organisations are almost equally distributed across all three supply chain positions. Eight organisations are active in both positions one and two. Seven organisations are active in position three. Loughborough University is the most active in terms of publishing in this cluster with 29 publications, followed by Rolls Royce with 20 publications. Three universities have 10 or more publications each: Nottingham (16), Warwick (13) and Sheffield (10). Together these five organisations, Loughborough, Rolls Royce, Nottingham, Warwick and Sheffield, account for 88% of the 114 publications produced by this cluster. While the universities publish across different sectors, with Rolls Royce playing such a major role the cluster could be described as having a focus on the aerospace sector.

The West cluster around Cardiff in Wales has 15 organisations and is dominated by nine universities. The most active universities in terms of publications are the West of England (16) and Exeter (12). The cluster only includes four companies, however two of these publish more than both universities – Renishaw with 28 publications and Airbus with 22. Together these four organisations dominate the cluster with 92% of all 86 publications. The organisations in this cluster are unevenly distributed across the positions of the supply chain. Nine out of the 15 organisations are active in position three, four in position two and only two in position one. Apart from Airbus and Renishaw and their activities in the aerospace and machinery sectors, the cluster does not seem to have a clear focus on any particular economic sector.

Finally, there appears to be a fourth cluster located within the Greater London area. This cluster has 21 organisations of which seven are universities, six are companies and four are hospitals. In addition the cluster includes one charity (Orthopaedic Research UK), one museum (National History Museum), one research institute (Institute for Cancer Research) and one governmental organisation (National Physical Laboratory). The 21 organisations together have produced 52 publications, of which 35 (67%) come from universities. UCL is the most active with 15 publications followed by Imperial College with 10 publications. The rest of the publications are largely divided across the remaining organisations. Companies in the cluster tend to be small, with none having more than one publication. With four publications, Brunel University is the only one of the remaining organisations with more than two publications. More than half of this cluster (12 organisations) is active in supply chain position three. Five organisations are active in position one, and four in position two. The cluster appears to be clearly focused on health and pharmaceuticals. Seventy nine per cent, or 41 of the 52 publications in this cluster, relate to AM activities in health and pharmaceuticals, with 13 out of the 21 organisations strongly linked to this sector.

A number of AM-active organisations appear to be located outside London – to the north, the east and the west and a very few towards the south. However, a closer examination of the data does not reveal any particular pattern that would justify describing this as an additional cluster.

In summary, none of the clusters seems to particularly stand out in terms of size. The clusters range from 15 (West) to 23 (Midlands) organisations. Comparing the clusters very crudely by 'productivity' (i.e. publications per organisation) reveals that the West cluster, around Cardiff in Wales, is the most productive with 5.7 publications per organisation, followed by the Midlands cluster with a productivity of 5.0 publications per organisation. The Greater London cluster has the lowest productivity of 2.5.

4 Conclusions

This report finds that the UK has a relatively small additive manufacturing sector with 121 organisations actively patenting or publishing papers. Eighty per cent of all organisations are either companies or universities. Hospitals make up the third largest group of AM-active organisations. The 121 organisations have filed 151 patent families and 362 scientific or technical publications from 2006 to 2015. On average that is 1.2 patents and three publications per organisation. Only 16 of these 121 organisations have filed two or more patents. The top four patentees, with more than ten patent families each, are Renishaw, Rolls-Royce, Airbus and BAE Systems. The top five publishing organisations are Loughborough University, University of Manchester, University of West of England, University of Nottingham and University College London. All the top 20 publishing organisations are universities. Companies tend to file more patents, while universities are more active with journal articles and papers. The low patenting figures revealed by this study correspond with the previously observed low patenting propensity of UK firms (e.g. Hall 2013).

The organisations studied are mostly active in three economic sectors, namely health and pharmaceuticals, aerospace and education. This is closely aligned with the general economic profile of the UK. Thirty-four organisations appear to be active across multiple sectors. These are mostly universities but include one company (Renishaw). Surprisingly, we found very few AM-active organisations linked to the automotive sector. While the UK has organisations active at all positions of the supply chain, the majority operate in later parts of the supply chain. This includes industrial users and those providing services and software as well as post-processing of components and products. We found that innovations are not always applicable to a single technology such as Directed Energy Deposition (DED), or binder jetting, but are becoming more industry specific, to be expected in a maturing technology. The study also found that new materials are under development specifically for AM. This was noted in particular for metal-based AM methods, such as DED and Powder Bed Fusion (POBF). In our dataset we found hardly any evidence of sheet lamination and very few activities related to material or binder jetting.

From our analysis of the geographical spread of the organisations, the economic sectors in which they are active and their supply chain positions we conclude that there seem to be four AM clusters in the UK. Cardiff forms part of a West cluster with Bristol and Bath in England. Other clusters were identified in the Midlands centred around Loughborough, Nottingham and Sheffield, and focusing on high technology and manufacturing; and in the north around Liverpool and Manchester. A substantial number of companies are found within the M25 ring road, forming the Greater London cluster, with a clear emphasis on the health and pharmaceutical sector. None of the clusters particularly stand out in terms of size. The clusters range from 15 organisations (West) to 23 (Midlands). Comparing the clusters in terms of innovative productivity (i.e. publications per organisations) reveals that the West cluster around Cardiff in Wales is the most productive with 5.7 publications per organisation, followed by the Midlands cluster with a productivity of 5.0 publications per organisation. The Greater London cluster in London has the lowest productivity of 2.5.

The conclusions of this study are based on a dataset of patents and publications filed or published between 2006 and 2015. We are aware that UK-based organisations were highly influential in developing AM technologies in the early days of AM – however, this was a period prior to our dataset. Based just on our data, it seems that only a relatively small number of UK-owned organisations have been pushing the limits of the technology in the last decade.

We would like to remind the reader that while we have tried our best to develop a comprehensive and complete dataset, given the limitations of the project the dataset may well be incomplete. This study relied on using the generic terms for 'additive manufacturing' and its classifications in the CPC/IPC as the primary search tools. This means the total AM field may have been underrepresented, as papers and patents focused on highly specific work involving a particular technique could have been missed. Nevertheless, we hope that the insights gained from this project will be helpful, not only for the UK but also for the international AM community.

As with any such enquiry, further questions have emerged during the course of the study in addition to those we have addressed. More work is needed to understand how small and large AM-active companies use patenting and publishing strategically, and how they develop their IP strategy

to build their businesses. It might also be of interest to review IP held by AM companies that are then acquired by others and to consider why they have been taken over. Maybe they have been the owners of large IP portfolios. Another fruitful avenue for further research could be to examine how those companies filing patents are managing their portfolios. Future research could also focus on particular economic sectors.

In this study we were able to categorise two thirds of the dataset by AM activity. It is clear, however, that many organisations are developing new methods, materials and techniques which may benefit more than one AM technology and also that new overlapping technologies are emerging, such as nano-manufacturing. New materials, specifically for AM, are also being developed, and these could be the focus of future study.

While we have identified AM-related standards (see Appendix 6.8) further research could examine how the standards relate to the AM categories and economic sectors, as well as how UK organisations might contribute to developing AM standards further and to their use strategically. In terms of methodology we would like to see further validation of the AM categories. Each organisation in our dataset was categorised initially according to the seven ASTM-defined technologies. However, we found additional categories were needed to reflect the breadth of activities in our data, and we therefore added seven further categories. The additional categories relate to 1) innovations occurring in supporting technologies, e.g. software, materials, post-processing; 2) overlapping techniques between two or more of the seven ASTM-defined technologies; and 3) a new type of AM activity, namely additive nano-manufacturing.

5 Bibliography

Baumann, F., T. Ludwig, N. Darwin Abele, S. Hoffmann and D. Roller (2017). Model-Data Streaming for Additive Manufacturing Securing Intellectual Property. Smart and Sustainable Manufacturing Systems 1(1): 142-152.

Greene, T. (2017). Industrial 3D Printing/Additive Manufacturing – Adding to the Fundamental Value Proposition of Digital Printing. IMI. Orlando, Florida.

Gridlogics Technologies (2014). 3D Printing: Technology Insight Report - An analysis of patenting activity around 3D-Printing from 1990-Current, from http://www.patentinsightpro.com/techreports/0214/Tech%20Insight%20Report%20-%203D%20Printing.pdf

Hall, B. H. (2013). Is intellectual property important for future manufacturing activities? Future of Manufacturing Project: Evidence Paper 12; Foresight, Government Office for Science.

ISO/ASTM 5290 (2015). Standard Terminology for Additive Manufacturing – General Principles – Terminology. ASTM International, West Conshohocken, PA, 2015.

Li, J., C. Myant and B. Wu (2016). The Current landscape for additive manufacturing research - A review to map the UK's research activities in AM internationally and nationally. London, Imperial College.

Shirazi, S. F. S., S. Gharehkhani, M. Mehrali, H. Yarmand, H. S. C. Metselaar, N. A. Kadri and N. A. A. Osman (2015). A review on powder-based additive manufacturing for tissue engineering: selective laser sintering and inkjet 3D printing. Science and technology of advanced materials 16(3): 033502.

UK Additive Manufacturing Steering Group (2016). Additive Manufacturing UK, from http://www.ifm.eng.cam.ac.uk/uploads/Resources/Reports/AM_PUB_MTC_FINAL_FOR_PRINT_new_-_low_res.pdf

UKIPO (2013). 3D printing – A patent overview, from https://www.gov.uk/government/publications/3d-printing-a-patent-overview

6 Appendices

6.1 Preparation of datasets

Patents with a publication date after 2006 are included in the collection. Patents are published 18 months following publication. Thus, the dataset effectively includes patents with a priority date of 2015. To ensure consistency, papers were included up to 2015, even though more recent data was available.

Patent data

The dataset was built from two searches. First, the publication numbers from 2006 to date from an Orbit dataset, which was built on the UK IPO 2013 report, were used as the starting point for the project. These numbers were uploaded into Clarivate (formerly Thomson Innovation) to obtain the Derwent World Patents Index (DWPI) patent families. From this we extracted all patents with GB, WO, and EP priorities. We then removed all non-relevant documents and all patents from non-UK companies by manual screening, resulting in 77 DWPI families. Secondly, we carried out an additional search focused on the CPC classes B33 and B33Y with GB priority from 2006 onwards. This search identified 185 patent families. Both datasets were then consolidated resulting in 187 patent families. During another round of manual screening 36 were eliminated as not relevant arriving at a total of 151 patent families. The data collection was carried out between 3 March and 24 April 2017.

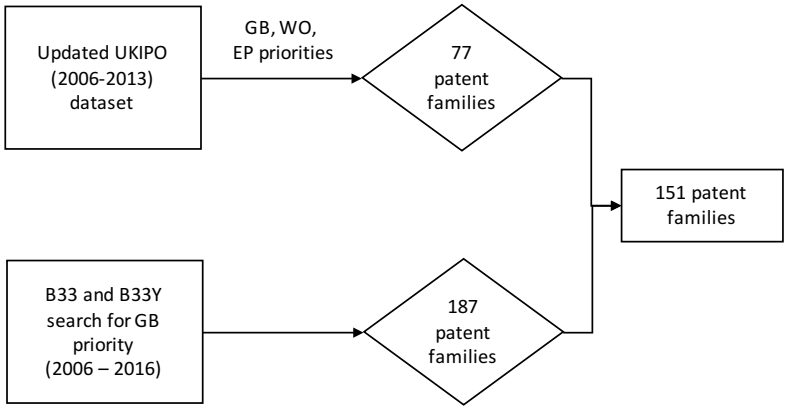

Figure 20: Preparation of patent dataset

Publications

Searches were carried out between 27 March and 24 April 2017. A high-precision search string was used for the paper search across 23 databases, consistent with the approach taken for the patent search. An 'all fields search' ((additive P/3 (manufact* or fabricat*)) OR (3D P/3 PRINT*)) AND af(UK or GB or Britain or England or Scotland or Wales) resulted in 3416 documents, which was then reduced to a 'title' search only (TI((additive AND (manufact* or fabricat*)) or (3D AND print*)) AND AF(UK or GB or Britain or England or Scotland or Wales)). This resulted in 589 publications after removal of duplicates. We excluded the 2016 publications to ensure we covered the same period as for patent documents. This resulted in a set of 382 publications. The dataset includes dissertations, which were not specifically searched for, but were not deliberately excluded if the search picked them up. Papers were downloaded from ProQuest by publication year for analysis.

Geographic analysis

To verify that publications related to UK organisations we identified the author/inventor and/or organisation's name and address to determine whether the organisation originated in the UK, or at least had its headquarters in the country and was in UK ownership at the time of publication.

Geographic studies of this type are problematic for two reasons. First, this information is usually available for all contributors in the original paper or the original patent application, but some information may be lost during the processing of the data, prior to its appearance in the secondary databases from which we downloaded the data. The reasons for this are several, including privacy and legacy systems which have not been designed to present this data for processing, resulting in the authors and their addresses being incomplete.

Relevancy checking

Any search will identify documents as relevant, which on closer examination turn out not to be for various reasons. Decisions concerning the subject relevance of patents were verified by an AM expert. Documents not AM-related were excluded. In particular, false hits came in relation to the following topics:

- Printing on three dimensional objects
- Three-dimensional fluidic device
- Fuel additive compositions
- Improvements to traditional plastic molding methods

Several documents were also eliminated from the publication dataset as not from the UK, e.g. New South Wales, Australia.

The following companies and their patents were eliminated from the original set of patent families due to non-UK ownership:

- Digital Metal AB
- Materialise NV
- Nobel BioCare
- SKF AB
- Sony Interactive Entertainment.

Other patents were deleted from the dataset if the companies involved had since been acquired by non-UK companies. Examples include:

- Materials Solutions (now owned by Siemens)
- Simpleware (bought by Synopsys)
- Materialise
- M Cor Technologies
- Pilkington Group (now owned by NSG)

6.2 AM technology categories

Categorisation of AM activities for the project was based on the seven types defined in the ASTM standard (ISO/ASTM 5290 2015). During our analysis we added six further technology categories. Organisations using multiple AM technologies were allocated as many categories as required. The general category 'AM' was allocated if it was not possible to identify the specific type of technology used by an organisation, or if it was engaged in an activity applicable to the whole sector.

The categories are shown in the table below in alphabetical order. **Bold text** indicates a new category we have created, and new synonyms we have found during the course of this project.

AM Category (Code)	Synonyms
Additive Manufacturing (AM)	3D printing; 3D modelling; digital manufacturing; Additive Layer Manufacturing (**ALM**), Rapid Prototyping, Rapid Manufacturing, Rapid Product Development, AM, solid free-form fabrication, **fused filament fabrication; additive printing; Fold Core Manufacturing Processes; layered object manufacturing (LOM); additive layer machining (ALM)**
Additive Nano Manufacturing (NANO)	**EHD jet printing; dip-pen lithography; direct laser writing; electro kinetic Nano manipulation**
AM product (ITEM)	**Any 3D-printed object**
Directed Energy Deposition (DED)	Powder feed; wire feed; laser metal deposition (LMD); plasma deposition; electron beam direct melting wire arc, electron beam welding, electron beam melting; arc welding, Laser blown powder, gas feed Is needed e.g. Ar. **Wire + arc AM (WAAM)**
Jetting - Binder (BINJ)	**Powder bed; inkjet head 3D printing; drop-on-powder; 3D printing (3DP); digital printing; laser printing; electrostatic printing**
Jetting - Material (MATJ)	Ink-jetting; metal jetting; **3D printing (3DP)**
Just In Time (JIT)	**Automated lab solutions preparation module; modular ICT equipment** *(Not really AM, but conceptually technologies which facilitate low inventory and immediate access to components, or equipment needed to make something.)*
Material (MAT)	**New material development/formulation specifically for AM; material selection methods**
Material Extrusion (ME)	Material co-extrusion; paste extrusions; extrusion; material deposition; **fused filament fabrication (FFF); plastic jet printing; fused deposition modelling (FDM)**
Post-processed feature (POST)	**Anything added to a 3D-printed product, such as: damage indicator; sensor; anything other than pure software**
Powder Bed Fusion (POBF)	Selective laser melting (SLM); electron beam melting (EBM); selective laser sintering (SLS); masked sintering; infrared sintering; directed metal laser sintering (DMLS); laser sintering; polymer sintering; laser powder bed; **high-speed-sintering**
Sheet Lamination (SHLA)	Ultrasonic consolidation; laminated object manufacture; adhesive lamination; **layered object manufacturing (LOM)**
Software (SOFT)	**Computer-aided design (CAD); other pre-printing and post-printing software**
Stereolithography (STLI)	Vat photopolymerisation; photopolymer, ceramic-loaded stereolithography; two-photon lithography (2lp), direct light processing (dlp); **electrophotography; digital light projection (DLP)**

6.3 AM materials and the AM technologies with which they may be used

METAL	POLYMER	PHOTOPOLYMER	CERAMIC	ORGANIC	BUILDING MAT	WAX
BINJ	BINJ		BINJ		BINJ	
DED						
MATJ		MATJ		MATJ		MATJ
	ME		ME	ME		
POBF	POBF	POBF				
SHLA			SHLA	SHLA		
		STLI	STLI			

6.4 Economic sectors

Fifteen economic sectors were used for the data analysis in this report. The sectors were based on those defined by the UK Additive Manufacturing Steering Group (2016) and derived from SIC codes. **Bold text** indicates a new sector, or term, added for this report.

Economic sector	Description
Aerospace & space (AERO)	Manufacture, repair and maintenance of air, spacecraft and related machinery
Automotive (AUTO)	Manufacture, maintenance and repair of motor vehicles, trailers, caravans, electrical and electronic equipment for motor vehicles
Business services (BUS)	Software development, IT consultancy, data processing, legal activities, business consultancy, technical testing and services, other R&D in natural sciences and engineering, specialised design services, **advertising**
Construction (CONS)	Construction of commercial and domestic buildings, bridges and tunnels
Consumer goods (CONG)	Manufacture and repair of footwear, ornamental articles, domestic appliances, jewellery, musical instruments, sports goods, professional and other games and toys, home and garden equipment, **decorative**
Defence (DEF)	Manufacture of weapons, ammunition and military fighting vehicles
Education (EDUC)	General secondary, technical, vocational, tertiary education and support services, **archaeology, chemistry laboratory equipment, instrumentation, flow chemistry**
Energy (ENER)	**Oil, gas, clean energy applications**
Food and drink (FOOD)	Manufacture of food and drink
General industrial (GENE)	Printing, manufacture of plastics, paints, technical, ceramic, metal structures and components
Health and pharmaceutical (HEALTH)	Manufacture of pharmaceutical preparations, medical and dental instruments and supplies, veterinary activities, orthotics
ICT (ICT)	**Telecommunications, electronics, semiconductors**
Machinery and equipment (MACH)	Manufacture and repair of tools, electronic equipment, electric motors, pumps and compressors, taps and valves, hand tools, metal forming machines, special purpose machinery, cooling and ventilation equipment
Transport (TRANS)	Manufacture, building and repair of railway locomotives and rolling stock, motorcycles, bicycles, invalid carriages, ships, pleasure boats, other floating structures
MULTIPLE (MULTI)	**Used when an organisation is active in >1 sector.**

6.5 B33 patent classification

The Cooperative Patent Classification (CPC) system came into force on 1 January 2013, as a bilateral system jointly developed by the European Patent Organisation (EPO) and the United States Patent and Trademark Office (USPTO). Since then it has been adopted more widely around the world by technologically-active patenting authorities. A new classification for 'additive manufacturing' (B33) was added to the CPC, and also to the International Patent Classification (IPC), to provide a one-stop class for this important, emerging technology. This single class was used to identify the documents to be included in the analysis. The CPC table of codes provides a detailed breakdown of all the CPCs found within the set, matched to the AM category. This set of codes could be used for further searches to broaden the set and for a more detailed analysis. The identical code has been available in the IPC since 2015. The IPC is not back-dated for search.

CPC scheme and definitions:
http://www.cooperativepatentclassification.org/cpcSchemeAndDefinitions.html

CPC COOPERATIVE PATENT CLASSIFICATION

B **PERFORMING OPERATIONS; TRANSPORTING**
(NOTES omitted)

SHAPING

B33 **ADDITIVE MANUFACTURING TECHNOLOGY**

B33Y **ADDITIVE MANUFACTURING, i.e. MANUFACTURING OF THREE-DIMENSIONAL [3-D] OBJECTS BY ADDITIVE DEPOSITION, ADDITIVE AGGLOMERATION OR ADDITIVE LAYERING, e.g. BY 3-D PRINTING, STEREOLITHOGRAPHY OR SELECTIVE LASER SINTERING**

NOTES

1. This subclass covers additive manufacturing, irrespective of the process or material used.
2. This subclass is intended to enable a comprehensive search of subject matter related to additive manufacturing by combination of classification symbols of this subclass with classification symbols from other subclasses. Therefore this subclass covers aspects of additive manufacturing (e.g. 3D printing) that might also be entirely or partially covered elsewhere in CPC.
3. This subclass is for obligatory supplementary classification of subject matter already classified as such in other classification places, when the subject matter contains an aspect of additive manufacturing.
4. The classification symbols of this subclass are not listed first when assigned to patent documents.
5. In this subclass, multi-aspect classification is applied, so that aspects of subject matter that are covered by more than one of its groups should be classified in each of those groups.

10/00	**Processes of additive manufacturing**
30/00	**Apparatus for additive manufacturing; Details thereof or accessories therefor**
40/00	**Auxiliary operations or equipment, e.g. for material handling**
50/00	**Data acquisition or data processing for additive manufacturing**
50/02	. for controlling or regulating additive manufacturing processes
70/00	**Materials specially adapted for additive manufacturing**
80/00	**Products made by additive manufacturing**
99/00	**Subject matter not provided for in other groups of this subclass**

Additive Manufacturing Technology subclass B33
http://www.cooperativepatentclassification.org/cpc/scheme/B/scheme-B33Y.pdf

6.6 CPC codes with 10 or more occurrences in the dataset linked to AM category

CPC	AM Category	Description
A23G1/0036	ITEM	Cocoa; Cocoa products, e.g. chocolate; Conching
A23G1/54	ITEM	Cocoa; Cocoa products; Composite products, e.g. layered laminated, coated, filled
A23G1/545	ITEM	Cocoa; Cocoa products; Hollow products, e.g. with inedible or edible filling, fixed or movable within the cavity
A23G2200/00	ITEM	Cocoa; Cocoa products, e.g. chocolate; containing organic compounds, e.g. synthetic flavouring agents
A23G2200/02	ITEM	Cocoa; Cocoa products, e.g. chocolate; containing micro-organisms, enzymes, probiotics
A23G3/40	ITEM	Sweetmeats; Confectionery; Marzipan; Coated or filled products; characterised by the fats used
A23G3/52	ITEM	Sweetmeats; Confectionery; Marzipan; Aerated, foamed, cellular or porous products
A23G3/545	ITEM	Sweetmeats; Confectionery; Marzipan; hollow products, e.g. with inedible or edible filling, fixed or movable within the cavity
A23V2002/00	ITEM	Food compositions, function of food ingredients or processes for food or foodstuffs
A61F2/30767	ITEM	Prostheses implantable into the body; joints; Special external and/or bone-contacting surfaces, e.g. coating for improving bone ingrowth
A61F2/3094	ITEM	Prostheses implantable into the body; joints; Designing or manufacturing processes (not used, see subgroups)
A61F2002/30929	ITEM	Prostheses implantable into the body; joints; having at least two superposed coatings
A61F2230/0093	ITEM	Prostheses implantable into the body; joints; Umbrella-shaped, e.g. mushroom-shaped
A61F2310/00011	ITEM	Prostheses implantable into the body; joints; Metals or alloys
A61F2310/00796	ITEM	Prostheses implantable into the body; joints; Coating or prosthesis-covering structure made of a phosphorus-containing compound, e.g. hydroxy(l)apatite
A61L27/04	MAT	Materials for grafts or prostheses or for coating grafts or prostheses; Metals or alloys
A61L27/06	MAT	Materials for grafts or prostheses or for coating grafts or prostheses; Titanium or titanium alloys
A61L27/306	MAT	Materials for grafts or prostheses or for coating grafts or prostheses; Other specific inorganic materials not covered by A61L27/303 - A61L27/32
A61L27/32	MAT	Materials for coating prostheses; Phosphorus-containing materials, e.g. apatite
A61L27/34	MAT	Materials for coating prostheses; Macromolecular materials
B01D46/0008	POBF	Filters , i.e. particle separators or filtering processes specially modified for separating dispersed particles from gases or vapours; Two or more filter elements not fluidly connected positioned in the same housing
B01D46/0058	POBF	Filters, i.e. particle separators or filtering processes specially modified for separating dispersed particles from gases or vapours; Regeneration; Devices for taking out of action one or more units of multi-unit filters
B01D46/0093	POBF	Filters, i.e. particle separators or filtering processes specially modified for separating dispersed particles from gases or vapour; provided with safety protection means; against fire or explosion
B01D46/2403	POBF	Filters; Particle separators, e.g. dust precipitators, using rigid hollow filter bodies; characterised by the physical shape or structure of the filtering element
B01J13/0047		Preparation of sols; containing a metal oxide (Colloid chemistry)
B05B1/02	MATJ	Spraying apparatus; Atomising apparatus; Nozzles designed to produce a jet, spray, or other discharge of particular shape or nature, e.g. in single drops, or having an outlet of particular shape (B05B1/26, B05B1/28, B05B1/34 take precedence)
B05B13/005	MATJ	Machines or plants for applying liquids or other fluent materials to surfaces of objects or other work by spraying, mounted on vehicles or designed to apply a liquid on a very large surface, e.g. on the road, on the surface of large containers
B05B13/0405	MATJ	Machines or plants for applying liquids or other fluent materials to surfaces of objects or other work by spraying, mounted on vehicles; with reciprocating or oscillating spray heads
B05B13/0431	MATJ	Machines for applying liquids or other fluent materials to surfaces of objects or other work by spraying, not covered by groups B05B1/00 - B05B11/00
B05B3/00	MATJ	Spraying or sprinkling apparatus with rotating elements located upstream the outlet
B22F2003/248	MAT (POBF / DED)	After treatment of articles by thermal treatment

CPC	AM Category	Description
B22F20031057	MAT (POBF / DED)	Specific treatments of metallic powder
B22F20031059	STLI	Selective sintering, i.e. stereo lithography (details of apparatus for cleaning and recycling)
B22F2301/056	MAT (POBF / DED)	Alkaline metals
B22F2301/058	MAT (POBF / DED)	Magnesium
B22F2998/00	DED	Shaping; Supplementary information concerning processes or compositions relating to powder metallurgy
B22F3/003	DED	Manufacture of workpieces or articles from metallic powder characterised by the manner of compacting or sintering; Apparatus, e.g. furnaces
B22F3/105	DED	...by using electric current other than for infra-red radiant energy, laser radiation or plasma (B22F3/11 takes precedence); by ultrasonic bonding (B22F3/115 takes precedence)
B22F3/1055	POBF / STLI	Selective sintering, i.e. stereo lithography (selective sintering of powdered plastics
B22F3/15	DED	Hot isostatic pressing
B22F7/04	POBF	Manufacture of composite layers, workpieces, or articles, comprising metallic powder, by sintering the powder, with or without compacting wherein at least one part is obtained by sintering or compression with one or more layers
B23K15/0086	DED	Electron-beam welding or cutting; welding for purposes other than joining, e.g. built-up welding
B23K2201/18	POBF / DED	soldering or welding
B23K2203/16	MAT	materials to be welded or cut or soldered
B23K2203/50	MAT	materials to be welded or cut or soldered
B23K26/032	DED	Working by laser beam, e.g. welding, cutting or boring; using optical means
B23K26/034	DED	Working by laser beam; Observing, e.g. monitoring, the workpiece/Observing the temperature of the workpiece
B23K26/342	DED	Build-up welding/Build-up welding
B23K35/0244	DED	Rods, electrodes, materials, or media, for use in soldering, welding, or cutting for use in soldering, brazing/Powders, particles or spheres; Preforms made therefrom
B23K35/0255	DED	Rods, electrodes, materials, or media for use in welding
B23K35/0272	DED	Rods, electrodes, materials, or media with more than one layer of coating or sheathing material
B25J11/0055	AM	Shaping - Cutting
B25J11/0075	AM	Manipulators for painting or coating
B25J15/0004	AM	Gripping heads with provision for adjusting the gripped object in the hand
B25J15/0019	AM	End effectors other than grippers
B25J5/007	AM	Shaping - Manipulators - mounted on wheels
B29C2071/022	ME, POBF	Shaping or joining of plastic material; thermal after treatment - annealing
B29C67/0051	POBF	Rapid manufacturing and prototyping of 3D objects by additive depositing, agglomerating or laminating of plastics material, e.g. by stereo lithography or selective laser sintering
B29C67/0055	POBF	...using only liquids or viscous materials, e.g. depositing a continuous bead of viscous material
B29C67/0077	ME, POBF	...using layers of powder being selectively joined, e.g. by selective laser sintering or melting/using layers of powder being selectively joined, e.g. by selective laser sintering or melting/using layers of powder being selectively joined, e.g. by selective laser sintering or melting
B29C67/0081	POBF	...using a combination of solid and liquid materials, e.g. a powder selectively bound by a liquid binder, catalyst, inhibitor or energy absorber
B29C67/0085	ME, POBF	Rapid manufacturing and prototyping of 3D objects by additive depositing, agglomerating or laminating of plastics material, e.g. by stereo lithography or selective laser sintering/Apparatus components, details or accessories
B29C67/0088	POBF (SOFT)	Rapid manufacturing; for control or data processing, e.g. algorithms
B29C67/0092	ME, POBF	Support structures for the 3D object during manufacture, e.g. using sacrificial material
B29C71/0009	ME, POBF	After-treatment of articles without altering their shape; Apparatus therefor e.g. using liquids, e.g. solvents, swelling agents

CPC	AM Category	Description
B29K2067/04	AM	Polyesters derived from hydroxycarboxylic acids
B29K2995/0054	AM	Properties of moulding materials, reinforcements, fillers, preformed parts or moulds - multi-axially
B32B37/144	AM	Methods or apparatus for laminating, e.g. by curing or by ultrasonic bonding - using layers with different mechanical or chemical conditions or properties, e.g. layers with different thermal shrinkage, layers under tension during bonding
B41M2205/32	AM	Thermal receivers
B41M5/0256	AM	Duplicating or marking methods; Sheet materials for use therein; the transferable ink pattern being obtained by means of a computer driven printer, e.g. an ink jet or laser printer, or by electrographic means
B41M5/0355	AM	Duplicating or marking methods; Sheet materials for use therein ; by transferring ink from the master sheet; by sublimation or volatilisation of pre-printed design; characterised by the macromolecular coating or impregnation used to obtain dye receptive properties
B41M5/44	AM	...characterised by the macromolecular compounds
B41M5/502	AM	...characterised by structural details, e.g. multilayer materials.
B41M5/52	AM	Macromolecular coatings
B41M5/5254	AM	...characterised by the use of polymers obtained by reactions only involving carbon-to-carbon unsaturated bonds, e.g. vinyl polymers
B44C1/1712	AM	Decalcomanias applied under heat and pressure, e.g. provided with a heat activable adhesive
B44C1/1716	AM	Decalcomanias provided with a particular decorative layer, e.g. specially adapted to allow the formation of a metallic or dyestuff layer on a substrate unsuitable for direct deposition
C01G49/02	MAT	Oxides; Hydroxides
C01G49/04	MAT	Ferrous oxide (FeO)
C01G49/04	MAT	Ferrous oxide (FeO)
C01G49/08	MAT	Ferroso-ferric oxide (Fe3O4)
C01P2006/22	MAT	Rheological behaviour as dispersion, e.g. viscosity, sedimentation stability
C01P2006/42	MAT	Magnetic properties
C09C1/0024	MAT	Treatment of specific inorganic materials other than fibrous fillers; pigments exhibiting interference colours, e.g. transparent platelets of appropriate thinness or flaky substrates, e.g. mica, bearing appropriate thin transparent coatings; comprising a stack of coating layers with alternating high and low refractive indices, wherein the first coating layer on the core surface has the high refractive index
C09J5/02	MAT	Adhesive processes in general; Adhesive processes not provided for elsewhere, e.g. relating to primers involving pretreatment of the surfaces to be joined
C10L1/02	MAT	Liquid carbonaceous fuels; essentially based on components consisting of carbon, hydrogen, and oxygen only
C10L1/08	MAT	...essentially based on blends of hydrocarbons for compression ignition
C10L1/10	MAT	Liquid carbonaceous fuels containing additives
C10L1/106	MAT	...mixtures of inorganic compounds with organic macromolecular compounds
C10L1/143	MAT	...mixtures of organic macromolecular compounds with organic non-macromolecular compounds
C10L1/1985	MAT	...polyethers, e.g. di- polygylcols and derivatives; ethers - esters
C10L1/206	MAT	...macromolecular compounds
C10L1/2227	MAT	...urea; derivatives thereof; urethane
C10L1/224	MAT	Amides; Imides carboxylic acid amides, imides (C10L1/221, C10L1/2227 take precedence)
C10L1/2283	MAT	...containing one or more carbon to nitrogen double bonds, e.g. guanidine, hydrazone, semi-carbazone, azomethine
C10L1/232	MAT	...containing nitrogen in a heterocyclic ring
C25D5/02	MAT	Electroplating of selected surface areas
C25D5/04	MAT	Electroplating with moving electrodes

CPC	AM Category	Description
E04B1/76	AM	Constructions in general; Structures which are not restricted either to walls, e.g. partitions, or floors or ceilings or roofs; Insulation or other protection;specifically with respect to heat only
E04F21/12	AM	Implements for finishing work on buildings acting by gas pressure, e.g. steam pressure
E04F21/16	AM	Implements for after-treatment of plaster or the like before it has hardened or dried, e.g. smoothing-tools, profile trowels
H05K2201/0347	AM	Overplanting, e.g. for reinforcing conductors or bumps; Plating over filled vias
H05K2203/0195	AM	Tool for a process not provided for in H05K3/00, e.g. tool for handling objects using suction, for deforming objects, for applying local pressure
H05K2203/0292	AM	Using vibration, e.g. during soldering or screen printing
H05K2203/101	POBF	Printed circuits; Casings or constructional details of electric apparatus; Manufacture of assemblages of electrical components; Using electrical induction, e.g. for heating during soldering
H05K3/1241	POBF	Apparatus or processes for manufacturing printed circuits; conductive surface preparation; by ink-jet printing or drawing by dispensing
H05K3/1241	AM	...by ink-jet printing or drawing by dispensing
H05K3/188	AM	...by direct electroplating
H05K3/246	AM	Reinforcing conductive paste, ink or powder patterns by other methods, e.g. by plating
Y02P10/295	BINJ/ DED / POBF/ MATJ / SHLA	Additive manufacturing of metals
Y10T002949826	POBF	Metal Working (former US class 70 series)
Y10T137/5362	POBF	Extensible spout
Y10T137/7794	POBF	With relief valve
Y10T29/49073	POBF	Electromagnet, transformer or inductor / by assembling coil and core
Y10T29/49815	POBF	Disassembling
Y10T29/53817	POBF	Valve stem pin or key and another member
Y10T403/42	AM	Rigid angle coupling, e.g. , elbow or u, etc.
Y10T403/4966	AM	Deformation occurs simultaneously with assembly
Y10T403/4974	AM	...by piercing
Y10T403/54	AM	Flexible member is joint component
Y10T403/73	AM	Rigid angle
Y10T428/24331	AM	Handling sheet or web including nonapertured component
Y10T428/24479	AM	...including variation in thickness
Y10T428/24521	AM	...with component conforming to contour of nonplanar surface
Y10T428/24612	AM	Composite web or sheet
Y10T428/24802	AM	...Discontinuous or differential coating, impregnation or bond [e.g., artwork, printing, retouched photograph, etc.]
Y10T428/265	AM	Web or sheet containing structurally defined element or component and including a second component containing structurally defined particles ; Coating layer 1 ml or less
Y10T428/31507	AM	Composite [nonstructural laminate] Of polycarbonate

Classification Codes can be found here:

CPC	https://rs.espacenet.com/classification?locale=en_EP
IPC	http://web2.wipo.int/classifications/ipc/

6.7 Sources – databases used and conferences identified

Databases used in the search for patents and literature

Patent databases

1. Cipher Database

Cipher database was used to create Figure 3. Cipher groups patents according to current owner and uses a proprietary technology clustering method.

Link: https://aistemos.com/

2. Derwent World Patent Index on Derwent Innovation

The Derwent World Patents Index (DWPI®) includes enhanced patent data from over 50 worldwide patenting authorities.

Patent families collect all patents related to the same invention in a single record. Patent documents from 50 worldwide patenting authorities and two journal sources are reviewed for an invention and the data is compiled and presented in a concise Patent Family Table. The DWPI Patent Family includes non-conventional equivalents, which can originate from applications that are filed by non-resident inventors in a country without claiming foreign priority, or applications that are filed outside the 12-month grace period (as stipulated by the Paris Convention).

Dates covered: 1963-present. **Data type**: Editorially-enhanced titles and abstracts. The rewritten patent titles are more detailed and aim to provide an insight into the new and unique features of each invention and how it is used. Language: English. **Update frequency**: Approximately every three days.

Link: https://www.thomsoninnovation.com

3. Total Patent

This database was used for inventor and applicant information to verify country of origin.

Link: https://www.lexisnexis.com/totalpatent/renderSearchForm.do

Coverage of UK documents in Total Patent:

Kind	Bibliographic Data	Full Text	PDF
Application	1782-07-04 — 2017-04-05	1855-08-14 — 2017-04-05	1859-08-05 — 2017-04-05
Grant	1870-11-04 — 2017-04-05	1916-01-31 — 2017-04-05	1916-01-31 — 2017-04-05

Scientific and technical literature

All databases were searched using ProQuest Dialog (27/03/2017 to 19/04/2017)
http://dialog.proquest.com/professional

1. Agricola (1970 - current)
2. Agris (1975 - current)
3. Biosis Previews® (1926 - current)
4. Cab Abstracts (1910 - current)
5. Chemical Business Newsbase (1985 - current)
6. Chemical Engineering & Biotechnology Abstract (1995 - current)
7. Earthquake Engineering Abstracts (1971 - current)
8. Ei Compendex® (1800 - current)
9. Ei EnCompassLIT (1999 - current)
10. Embase® (1947 - current)
11. FLUIDEX (Fluid Engineering Abstracts) (1974 - current)
12. FSTA® (1969 - current)
13. Inspec® (1898 - current)
14. International Pharmaceutical Abstracts (1970 - current)
15. Kosmet: Cosmetic Science (1968 - current)
16. Mechanical & Transportation Engineering Abstracts (1966 - current)
17. Medline® (1946 - current)
18. Paperbase (1975 - current)
19. Paperchem (1967 - current)
20. Pirabase (1975 - current)
21. Polymer Library (1972 - current)
22. SciSearch®: a Cited Reference Science Database (1974 - current)
23. Weldasearch® (1966 - current)

Conferences

AM techniques

International Conference on Digital Printing Technologies, IS&T, 2008-2015

Materials/end-uses

International Congress of the IUPESM. Medical Physics and Biomedical Engineering. World Congress: Biomaterials, Cellular and Tissue Engineering, Artificial Organs	IUPESM	2009
Multidisciplinary Design Optimization Conference	AIAA	2013
World Congress on Internet Security		2013
International Conference on Industrial Engineering and Engineering Management	IEEE	2015
International Association for Management of Technology Conference	IAMOT	2015
Advances in Information and Communication Technology	IFIP	
Fifth European Workshop on Optical Fibre Sensors		

Sustainability

5th International Conference on Responsive Manufacturing - Green Manufacturing

6.8 AM standards

ASTM F2924 - 14	2014	Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion
ASTM F2971 - 13	2013	Standard Practice for Reporting Data for Test Specimens Prepared by Additive Manufacturing
ASTM F3001 - 14	2014	Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium ELI (Extra Low Interstitial) with Powder Bed Fusion
ASTM F3049 - 14	2014	Standard Guide for Characterizing Properties of Metal Powders Used for Additive Manufacturing Processes
ASTM F3055 - 14a	2014	Standard Specification for Additive Manufacturing Nickel Alloy (UNS N07718) with Powder Bed Fusion
ASTM F3056 - 14e1	2014	Standard Specification for Additive Manufacturing Nickel Alloy (UNS N06625) with Powder Bed Fusion
ASTM F3091 / F3091M - 14	2014	Standard Specification for Powder Bed Fusion of Plastic Materials
ASTM F3122	2014	Standard Guide for Evaluating Mechanical Properties of Metal Materials Made via Additive Manufacturing Processes
ASTM F3184	2016	Standard Specification for Additive Manufacturing Stainless Steel Alloy (UNS S31603) with Powder Bed Fusion
ASTM F3184 - 16	2016	Standard Specification for Additive Manufacturing Stainless Steel Alloy (UNS S31603) with Powder Bed Fusion
ASTM F3187	2016	Standard Guide for Directed Energy Deposition of Metals
BS/ISO 17296-2	2015	Additive manufacturing – General principles – Part 2: Overview of process categories and feedstock
BS/ISO 17296-3	2014	Additive manufacturing – rapid technologies (rapid prototyping) Part 3: test methods
BS/ISO 17296-4	2014	Additive manufacturing – rapid technologies (rapid prototyping) Part 4: data processing
ISO/ASTM52900	2015	Standard Terminology for Additive Manufacturing – General Principles – Terminology
ISO/ASTM52901	2016	Standard Guide for Additive Manufacturing – General Principles – Requirements for Purchased AM Parts
ISO/ASTM52910	2016	Standard Guidelines for Design for Additive Manufacturing
ISO/ASTM52915	2016	Standard Specification for Additive Manufacturing File Format (AMF) Version 1.2
ISO / ASTM52921	2013	Standard Terminology for Additive Manufacturing-Coordinate Systems and Test Methodologies

Another set of standards are at the (WK) discussion stage.

6.9 Inventor patents not included in the analysis of organisations

Inventor	No. of patents	Category	Supply chain position	Industry	Patent family size	Filing date
SCOTT M	1	AM	3	CONG	1	25/08/2014
SHANMUGAM S	1	MAT	1	CONS	1	28/04/2014
SMITH A G	1	MAT	1	MULTI	1	13/08/2014
SMITH K	1	SOFT	2	MULTI	1	03/07/2013
TANN H	1	AM	2	MULTI	1	10/06/2010
TEBBITT J	1	STLI	2	MULTI	1	31/03/2006
WARD-CLOSE C M	1	DED	1	MULTI	5	24/02/2012
HALL L M | OLEARY J P	1	SOFT	3	CONG	1	16/01/2013
BURT M B	1	POBF	1	NOTDEF	1	03/07/2015
ATURELIYA S	3	AM	2	MULTI	2	01/01/2014
DENHOLM T	4	MATJ	2	CONS	1	01/01/2012

6.10 UK AM organisations included in this study with key data

Organisation	Total publications 2006-2016	Postcode (operational activities, not HQs)	Legal entity	AM category (technologies)	Supply chain position	Economic sector
3D 2.0 LTD	1	HA3 5QJ	CO	AM	2	MULTI
3D Alchemy	0	TF10 8HU	CO	POBF/STLI	2	MULTI
3T RAPID LTD	1	RG14 1AY	CO	POBF	2	MULTI
Added Scientific Ltd	0	NG7 2RH	CO	SOFT	2	MULTI
Addenbrookes Hospital	1	CB2 0QQ	HOS	AM	3	HEALTH
Advanced Weapons Establishment	2	RG7 4PR	GOV	SOFT	3	DEF
Airbus	22	BS99 7AR	CO	DED/POBF/ MAT/ME/POST	3	AERO
Amdel Medical Ltd	1	L18 2DH	CO	SOFT	3	HEALTH
Amec Foster Wheeler	1	E14 5LQ	CO	AM	3	ENER
Anglia Ruskin University	1	CB1 1PT	UNI	TEST	3	CONS
Assystem UK Ltd	2	PR5 6FN	CO	POBF	2	AERO
Aston University	1	B4 7ET	UNI	NANO	3	EDUC
BAE Systems plc	12	SW1Y 5AD	CO	POBF	3	AERO
Biocomposites Ltd	1	ST5 5BG	CO	MAT	1	HEALTH
Birmingham City University	1	B4 7BD	UNI	POBF	2	CONG
Blagdon Actuation Research Ltd	1	BS40 7TQ	CO	AM	3	AERO
Brunel University	4	UB8 3PH	UNI	MAT	2	MULTI
C4 Carbides Ltd	1	CB4 1TS	CO	DED	3	MACH
Carbon Fibre Preforms Ltd	1	B95 6AP	CO	AM	1	MACH
Cardiff Metropolitan University	2	CF5 2YB	UNI	SOFT	3	HEALTH
Cardiff University	3	CF10 3XQ	UNI	AM	1	EDUC
Cavendish Imaging	2	B15 3SJ	CO	AM	3	HEALTH
Cavendish Implants	1	W1G 8SB	CO	AM	3	HEALTH
Chas A Blatchford & Sons Ltd	1	S4 7QQ	CO	ITEM	3	HEALTH
Chelsea and Westminster Hospital	1	SW10 9NH	HOS	AM	3	HEALTH

Organisation	Total publications 2006-2016	Postcode (operational activities, not HQs)	Legal entity	AM category (technologies)	Supply chain position	Economic sector
CompactGTL LTD	1	OX14 1SY	CO	DED	3	EDUC
Cranfield University	11	MK43 0AL	UNI	DED/MAT	2	GENE
Croft Filters Ltd	1	WA3 6BL	CO	ME	2	MULTI
De La Rue International Ltd	1	RG21 4EA	CO	POST	3	BUS
De Montfort University	6	LE1 9BH	UNI	POBF/STLI	1	MULTI
Developa2 Ltd	1	SW6 1RP	CO	MATJ	1	MULTI
DST Innovations Ltd	1	CF31 3SH	CO	AM	3	ICT
East Anglian Radiography Research	1	NR4 7TJ	HOS	SOFT	3	EDUC
Epsom and St Helier University Hospitals NHS Trust	2	SM5 1AA	HOSP	POBF	1	HEALTH
Ex Scintilla Ltd	2	DE12 6EJ	CO	AM	2	MULTI
Fabrx Ltd	1	WC1N 1AX	CO	ME	3	HEALTH
Foster and Partners	1	SW11 4AN	CO	MATJ	3	CONS
Freeman Technology Ltd	1	GL20 8DN	CO	MAT	1	MULTI
Fripp Design Ltd	2	S60 5WG	CO	AM	2	HEALTH
GEOLA Technologies Ltd	1	BN1 9SB	CO	AM	1	MACH
GKN Aerospace	2	LU2 9PQ	CO	MAT/DED	2	AERO
Heriot Watt University	5	EH14 4AS	UNI	TEST/AM/POBF	2	DEF
Hybrid Manufacturing Technologies Ltd	1	DE12 6EJ	CO	DED	2	MULTI
Imperial College London	10	W1B 5AD	UNI	MATJ/MAT/SOFT	3	HEALTH
InfusionTech Systems (Tim Warwick)	2	HA3 8BY	CO	ME	1	MULTI
Institute of Cancer Research	1	SM2 5NG	RES INST		2	HEALTH
Invibio Materials Solutions	0	CO3 3BZ	CO	MAT	2	HEALTH
Johnson Matthey plc	3	SG8 5HE	CO	POBF/DED	3	MULTI
Kent Community Health NHS Foundation Trust	1	TN25 4AZ	HOSP	SOFT	3	HEALTH
Kent Community Health Trust	1	ME15 7AT	HOSP	SOFT	3	HEALTH
King's College, London	1	WC2R 2LS	UNI	AM	1	EDUC
LabMinds Ltd	1	6HJ, UK	CO	JIT	2	EDUC
Lancaster University	11	LA1 4YW	UNI	MAT/SOFT	1	MULTI
Loughborough University	29	LE11 3TU	UNI	POBF/MATJ/STLI	3	MULTI
M&I Materials Ltd	1	M32 0ZD	CO	POBF	2	AERO
Makieworld Ltd	2	BN44 3TN	CO	SOFT	3	CONG
Manchester Metropolitan University	1	M15 6BH	UNI	AM	2	HEALTH
Manufacturing Technology Centre	1	CV7 9JU	RES INST	AM	2	MACH
Metrology Software Products Ltd (Renishaw)	1	NE66 2DE	CO	AM	3	AERO
Modaptix Ltd	1	CB1 2LA	CO	JIT	2	ICT
National Museum Wales	1	CF10 3NP	MUS	SOFT	3	EDUC
National Physical Laboratory	1	TW11 0LW	GOV	AM	2	MACH
Natural History Museum	1	SW7 5BD	MUS	AM	3	EDUC
Newbourne Solutions Ltd	5	IP12 4NR	CO	AM	3	EDUC
Newcastle University	0	NE1 7RU	UNI	MAT	1	HEALTH

Organisation	Total publications 2006-2016	Postcode (operational activities, not HQs)	Legal entity	AM category (technologies)	Supply chain position	Economic sector
Newport Museum and Heritage Services	1	NP20 1PA	MUS	AM	3	EDUC
NHS England	1	LS2 7UE	GOV	AM	3	HEALTH
Northumbria University	1	NE1 8ST	UNI	MAT	2	MULTI
Nottingham Trent University	1	NG1 4FQ	UNI	AM	1	CONS
Orthopaedic Research UK	1	W1G 9DQ	CHAR	MAT	3	HEALTH
Oxford (ISIS Innovation Ltd)	5	OX2 0JB	UNI	MATJ	3	HEALTH
Peacocks Orthotics Ltd	1	SO16 0AJ	CO	AM	3	HEALTH
Printed Structures Ltd	1	CB24 9NU	CO	AM	1	AUTO
Publiavia Ltd	1	SG18 0AP	CO	POST	3	BUS
Queen Mary and Westfield College	1	E1 4NS	UNI	AM	1	HEALTH
Queen's University, Belfast	4	BT7 1NN	UNI	POBF/MAT/ MATJ	1	HEALTH
Quill International Group Ltd	1	DE73 8JB	CO	POST	3	MULTI
Renishaw plc	28	GL12 8JR	CO	POBF	2	MULTI
Rolls-Royce plc	20	SW1E 6AT	CO	POBF	3	AERO
Royal College of Art	1	SW7 2EU	UNI	AM	3	HEALTH
Royal Derby Hospital	1	DE22 3NE	HOS	SOFT	3	HEALTH
Royal Marsden NHS Foundation Trust	2	SW3 6JJ	HOS	MATJ	3	HEALTH
Royal Preston Hospital	1	PR2 9HT	HOS	MAT	3	HEALTH
Southend University Hospital	2	SS0 0RY	HOS	MATJ	3	HEALTH
Stage One Creative Services Ltd	1	YO26 7QF	CO	MAT	2	CONS
South West London Elective Orthopaedic Centre	2	KT18 7EG	HOS	POBF	3	HEALTH
Things 3d Ltd	4	CH1	CO	SOFT	3	MULTI
TWI Ltd	2	CB21 6AL	RES INST	DED/MAT	2	MULTI
UCL (University College London)	15	WC1E 6BT	UNI	ME	1	HEALTH
Univeristy Nottingham Hospitals NHS Trust	0	NG5 1PB	HOSP		3	HEALTH
University College Cardiff	2	CF10 3XQ	UNI	AM	2	MULTI
University of Bath	1	BA2 7AY	UNI	SOFT	3	MULTI
University of Birmingham	3	B15 2TT	UNI	POBF	2	HEALTH
University of Bradford	1	BD7 1DP	UNI	AM	1	HEALTH
University of Bristol	3	BS8 1TH	UNI	AM	2	HEALTH
University of Cambridge	8	CB2 1TN	UNI	AM	1	MULTI
University of Central Lancashire	4	PR1 2HE	UNI	ME/SOFT	1	MULTI
University of Dundee	2	DD1 4HN	UNI	MAT	1	HEALTH
University of East Anglia	2	NR4 7TJ	UNI	MATJ	3	HEALTH
University of Edinburgh Medical School	1	EH16 4TJ	HOS	AM	3	HEALTH
University of Essex	3	CO4 3SQ	UNI	AM	1	ICT
University of Exeter	12	EX4	UNI	DED/MAT/ SOFT	1	MULTI
University of Glasgow	12	G12 8QQ	UNI	MAT/MATJ/ NANO	1	MULTI
University of Greenwich	3	SE10 9LS	UNI	AM	3	HEALTH
University of Kent	6	CT2 7NZ	UNI	MATJ	3	CONS
University of Leeds	5	LS2 9JT	UNI	MAT	3	AERO

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University of Liverpool	6	L69 3BX	UNI	SOFT	1	HEALTH
University of Manchester	17	M13 9PL	UNI	MATJ/DED/ POBF	1	MULTI
University of Nottingham	16	NG7 2RD	UNI	MATJ/TEST/ SOFT	1	MULTI
University of Sheffield	10	S10 2TN	UNI	DED/SOFT/ POBF	1	MULTI
University of Southampton	4	SO17 1BJ	UNI	SOFT/AM	2	MULTI
University of Strathclyde	3	G1 1XQ	UNI	AM	1	MULTI
University of Wales	1	CF10 3NS	UNI	AM	3	EDUC
University of Warwick	13	CV4 7AL	UNI	MAT/DED/ STLI/BINJ	1	MULTI
University of the West of England	16	BS16 1QY	UNI	MAT/SOFT	2	CONG
University of Wolverhampton	1	WV1 1LY	UNI	POBF	1	MULTI
University of York	1	YO10 5DD	UNI	MATJ	3	HEALTH
Victrex Ltd	1	S61 4QH	CO	POBF	2	MULTI
Western General Hospital	1	EH4 2XU	HOSP	AM	3	HEALTH
Whispering Gibbon Ltd	1	NE1 6UF	CO	SOFT	1	CONG

Report authors

Jane List is the founder of Extract Information, providing consultancy, search services and training, all with a focus on commercial uses of patent information. She is Editor in Chief of World Patent Information, an Elsevier journal, and is an active member of the patent information professional community. Jane co-founded the Cambridge Information and IP Meeting (CIIPM) in 2015 to host an annual meeting and provide training in IP, information and commercialisation matters.

Frank Tietze is Lecturer in Technology and Innovation Management at the University of Cambridge, Department of Engineering. At the Centre for Technology Management he leads the Innovation and Intellectual Property Management research group. Frank serves on the Exploitation Committee of Chartered Institute for Patent Attorneys (UK) and is a member of the UKIPO Research Expert Advisory Group for Registered Rights. He is Affiliate at the Cambridge Centre for Intellectual Property and Information Law and member of the Innovation and IP research group at Chalmers University of Technology (Sweden).

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