The UK Additive Manufacturing Landscape

A Data-Centric Review of AM Innovation and Entrepreneurship 2010-2020 based on Public Spending

August 2022

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The work was carried out by Added Scientific Ltd and Meta consulting LDA.

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SUMMARY

Additive Manufacturing (AM) or 3D printing (3DP) describes the production of parts using a wide variety of digitally controlled manufacturing machines that add material where required, usually layer by layer, rather than subtracting or forming material in moulds.

AM has grown significantly over the last 35 years and was valued at €7.17 billion in 2020, €8.33 in 2021 (CAGR 16.2%) with a predicted growth to €19.23 billion by 2026 (CAGR of 18.2%) (AM Power, 2022). Prime moving sectors include aerospace, medical devices, automotive and the creative industries amongst others. AM was originally used for model making and rapid prototyping but has recently been widely adopted in many sectors for a plethora of end-use applications.

Several reports have been made since 2012, detailed later, that have analysed the UK's AM industry in relation to its global position. These reports indicated that the UK's research community was, at the time of their publication, well-established, globally respected, well equipped and funded. This current report was commissioned to analyse whether this was still evident and to investigate the effectiveness of the current AM research community with a particular focus on the commercialisation of research outputs, IP capture and spin-out formation and development.

Results of the analysis are positive in parts, where it can be concluded that firstly the funding of AM at a fundamental research level within the UK is at the expected level considering the popularity of AM as a topic for academics. Similarly, the funding of RTOs, such as the Catapult network, is also at a very healthy level. Research publication in academic journals remains high with UK researchers ranking among the top 5 academic authors globally. The impact of the pandemic has unsurprisingly had an effect, but it will take time to fully assess any impact.

Analysis of the AM funding and publication rates positive; it is clear that the UK has evidence of start-ups gaining traction but it is concerning that many of these start-ups are quickly acquired by larger, overseas technology companies, irrespective of the Technology Readiness Level (TRL) level involved. It is worth noting that the University research base has performed significantly better than RTOs in patenting their work. This is possibly a result of the emphasis placed on Impact within grant applications and the need to submit impact case studies for external benchmarking, such as the Research Excellence Framework (REF). Although these requirements are often disliked by the more 'fundamental' researchers, it does seem to have had an effect, with patent applications from Universities significantly exceeding that published by RTOs.

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The creation of successful spin-out companies formed as a result of funding is evident in the research base; however, the survivability of these businesses as UK-owned, UK-operated and significant profit-making businesses is in doubt. If funding for AM is to continue long-term then it is recommended that a considered strategy for exploitation beyond that which currently exists is required.

The UK research base in AM has the creativity and a growing willingness to garner IP and create impactful companies. However, without further support, it will be challenging for these start-ups to gain a foothold and withstand the pressures of the competitive nature of AM and resist takeover.

The authors note also that there are very-limited high-level strategic collaborations between the UK's fundamental research base and our Catapult/RTO network and suggest that this will create a medium-TRL vacuum with little pull-through.

It is noteworthy that many of the recommendations from previously commissioned reports have not yet been actioned.

Recommendations

It is clear that the UK continues to perform well in relation to international peers in all academic related areas for Additive Manufacturing – publications, grant income, collaborative projects with industry, PhD completions, etc.

However, it is equally clear that, despite some excellent examples to the contrary where both licencing and spin outs have been formed, the UK overall performs relatively poorly for spin out and value generation activities – particularly when considering long term, sustainable businesses that remain UK owned and operated. It should be noted that this is an issue that goes substantially beyond the area of just Additive Manufacturing and speaks to more of a structural problem for the UK in terms of commercial exploitation of research outcomes in general. However, here we make some recommendations that could help address this situation specifically for the Additive Manufacturing community so that the UK can become not only an AM research powerhouse, but an industrial one also.

What would we recommend to drive the required change

It is considered that one of the primary challenges that constrains the level of commercial exploitation from the UK's academic research community lies in the measures that are used to judge academic performance. In large part, current metrics for academic promotion and recognition apply significantly greater weight to academic related metrics rather than to commercial activity – i.e. in, the need for high quality publications as opposed to specific expectations around intellectual property that can then be used as a basis for forming a spin out activity. As such, researchers are likely missing valuable opportunities to exploit the outcomes of their research.

We believe that far more consideration should be given to IP generation and that IP/know-how exploitation (licensing / spin outs) should be significantly more rewarded and recognised by institutions to encourage research staff to engage more fully with exploitation. It is also recommended that metrics be put in place for the RTO/Catapult network to encourage both

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generation and protection of IP that can then be either licensed or spun-out, as currently the commercial outputs of the UK's RTO/Catapult network in the AM space are limited.

How do we develop the Entrepreneurial Culture within Universities & RTOs/ Catapults

Academic involvement in spinouts can take various guises, for example from acting as non-executive Directors with minimal day to day involvement through to academics taking on positions within the C-suite of a spinout. However, several challenges exist in terms of the formation of spinouts including: lack of knowledge / education for academics on best practice of how to exploit their work commercially; sufficient incentivisation for them to do so; alongside workload challenges in engaging with them.

Though it is clear that there is an opportunity for both university-based researchers and RTOs/Catapults to patent more, often the spinout policies of universities can also act as disincentives. A recent report from the University of Cambridge (downloadable here) provides an insightful overview of the disparate approaches taken by different universities to creating spinouts, with particular reference to founding equity positions of the Universities and inventor-founders. Whilst the median value of university shareholding is now 33%, there are often significantly higher equity positions required from universities (>50%) that discourage academics / researchers in forming spinouts. This is especially the case when there are two or more founders, thereby giving them a limited initial shareholding and creating limited incentives to engage in the spinout.

Given that the "team" is crucial to taking spinouts forwards, large shareholdings by Universities are also often cited by other potential new investors on the basis that founding directors are not incentivised to drive

It is recommended that Universities urgently address the equity positions at formation to both incentivise founders and enable investment funds to engage. Further, when looking at the geographical distribution of research activity within the AM field it is also clear that there is a mis-match between where the innovation and research activity is taking place and where the larger investment funds are sited. Is the UK missing out purely because the UKs research strengths within AM lie predominantly outside of the South East and London?

How do we encourage Co-ordination between the Research Institutes/ Facilities?

Given that many Additive Manufacturing spin out opportunities are based around multi-disciplinary, engineering-based endeavours, this speaks to the need to for significantly improved coordination between research institutes, faculties and RTOs.

There is a real danger that the UK misses the opportunity to lead?

Analysis from this report highlights that the UK punches above its weight in terms of Additive Manufacturing research – this has occurred over many years and is a long-term benefit to the reputation of the UK.

However, commercial activity is decidedly limited and we hope that the recommendations of this report will be actioned by RTOs, Universities and potential Founders so that the UK can also commercially prosper in the ever-expanding field Additive Manufacturing.

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01. INTRODUCTION

Additive Manufacturing (AM), commonly referred to as 3D Printing (3DP), describes numerous technologies that allow the automatic production of components from digital data whereby material feedstock is added to the part sequentially, layer-by-layer, until the final part is completed.

Adequately describing AM processes is a complex and lengthy task and the reader is directed to the following publications (Hopkinson, Hague, & Dickens, 2006), (Gibson, Rosen, & Stucker, 2016) and (Kumar, 2020) that describe the many AM processes in detail.

Aim and Objectives

This report aims to undertake an economic and technological assessment of UK AM research and innovation. To achieve the aim, the following objectives were set:

1. Describe AM its technologies and application areas
2. Assess the efforts made so far in encouraging AM application in the UK
3. Assess the UK funding landscape, including a regional breakdown of funding
4. Assess the recent historical performance of the UK's commercial and research base in AM over the following
   a. Knowledge generation
   b. Commercial exploitation
   c. New business generation
   d. Research base performance
5. To benchmark performance metrics internationally
6. Assess the potential for AM in creating new sectors and industry clusters as well as its capacity to enable existing businesses to deliver innovative solutions. For example, to socio-technical problems such as energy consumption and the movement to a net-zero economy.

In doing so, this report seeks to understand the opportunities and barriers to successful AM research, development and exploitation in the UK and to suggest ways in which these opportunities might be realised and optimised.

AM Technology and Application Areas

The American Society for Testing and Materials (ASTM) has classified AM technologies using the seven categories shown in Table 1 (ASTM, 2021). Although not an exhaustive list of technologies, this is a "snapshot" of leading AM approaches and activity in this space. It is intended to act as a guide to the key processes and technology platforms. There have also been developments in hybrid technologies that combine an additive process described in Table 1 with traditional manufacturing technologies such as CNC machining.

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> The typical advantages of AM as exploited by the aerospace industries includes the digital manufacturing chain

Table 1 ▼ Additive Manufacturing Process Categories

Category	Acronym	Description
Binder Jetting	BJT	A liquid bonding agent is selectively deposited to join powder materials
Directed Energy Deposition	DED	Focused thermal energy is used to fuse materials by melting as they are being deposited
Material Extrusion	MEX	Material is selectively dispensed through a nozzle or orifice
Material Jetting	MJT	Droplets of build material are selectively deposited
Powder Bed Fusion	PBF	Thermal energy selectively fuses regions of a powder bed
Sheet Lamination	SHL	Sheets of material are bonded to form an object

Applications of AM are diverse and the reader is directed towards the previous reviews which adequately describe the many uses of AM.

Suffice it to say that AM has been applied to many industries, the most important of which are listed below.

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AM in Aerospace

Aerospace companies were some of the first to adopt AM, initially using polymeric parts for the production of design prototype models and patterns for investment castings. Latterly the utility of AM saw it used for cosmetic aircraft interior components, complex low-temperature environmental control system ducting and tooling for composite parts. AM's ability to consolidate part numbers and the performance advantages conferred by complex free-form designs has resulted in a reasonable uptake as a manufacturing technology within aerospace industries. Recently, metallic AM systems such as Electron Beam and Laser-based melting processes, have been adopted for lightly loaded structures and static engine components, the most widely referenced component being the LEAP fuel nozzle developed by GE. AM has also found fertile application in the production of rocket nozzles for launch vehicles where parts consolidation and freeform design are being exploited. A detailed review of AM in aerospace can be found in (Froes & Boyer, 2019).

The typical advantages of AM as exploited by the aerospace industries includes the digital manufacturing chain, the lack of significant design constraints in comparison to other manufacturing technologies, the thermal and structural optimisation possibilities brought about by topology optimisation and/or generative design, new material possibilities (such as high entropy alloys), cost reduction via parts consolidation, legacy part production and the shortening of supply chains.

Future applications may include the deployment of AM in the manufacturing of larger fully loaded structures such as those explored by a range of DED technologies, particularly WAAM (Wire Arc AM) and cooling applications and integrated electromechanical systems such as those proposed by Moog.

Throughout this journey the barriers to the application of AM are twofold:

- Cost: in particular machine costs per part which is exacerbated by high initial investment, expensive maintenance and low production rates
- Qualification/standardisation issues: particularly material properties and process control.

AM in Medicine

A review of the Medical applications of AM can be found in (Banga, Kumar, Kalra, & Belokar, 2022). The first applications of AM in medicine were in the production of parts from patient-specific CT scan data used for preoperative planning and cutting templates for surgery. Bio-compatible materials were developed that enabled custom saw and drill guides to be used in surgery which conferred considerable advantages including, improved accuracy and cut complexity. The advent of metal-based AM using common biomedical alloys allowed the development of manufacturing processes enabling the production of implantable devices such as Total Knee Replacements (TKR) and Total Hip Replacements (THR). Here they ability of AM to manufacture digitally derived porous-structured materials enabled the regulation and sale of sized, cement less, implant systems that utilised the host's biological response to fix implants in place.

The fact that AM has been used to manufacture sized components is important because AM is regularly used to manufacture patient-specific devices.

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Sized devices represent a counterintuitively more difficult segment to exploit as regulations have historically tended to be more stringent, risks are higher – because of more significant numbers of implantations – and manufacturing has to cope with larger production rates which necessitate high initial investment in factories and capital equipment. Typical examples of patient specific devices developed to exploit the benefits of AM would be hearing aids, where personalised fit allows the hearing aid to both be more comfortable and discrete and dental aligners where complex temporal planning of tooth movement coupled with AM to provide known load and good fit enables at home tooth alignment.

AM is also used in the production of patient-specific implantable orthopaedic devices where the design freedom and digital link to CT scans are used to treat severe diseases such as cancer and severe osteolysis. Similarly, the link to CT scans has enabled considerable exploitation to be undertaken in dentistry where both polymeric and metallic systems have been used very successfully for the production of dental caps and crowns and invisible dental braces or aligners.

Currently, there are two main advantages of using AM in medicine, firstly the link to CT scan data allows the production of patient-specific implants, presurgical models, tools and cutting guides and secondly the design opportunities afforded by AM allow new treatments and implant systems to be developed and deployed rapidly.

Popular research topics for AM in medicine include the development of biomaterials to manufacture implants that resorb, the development of controlled release oral dosages that are customized to a particular patient or disease and the development of AM machine systems that produce meso and micro-scale prints that can be used to make a range of small medical devices. Recently it has been mooted that the production facilities could be moved to hospitals to speed the delivery of components to the medical practitioners involved and improve design effectiveness through better communication.

Typical barriers to AM's use in medicine include cost, speed, verification and validation and obtaining regulatory approval for use. However, it should be noted that the use of AM within medicine is very well adopted and effective in its current guise, being widely accepted by practitioners as providing the gold standard in many settings.

AM in Transportation

Vehicle development requires intensive design and development effort and this is where additive manufacturing initially found a foothold in the industry, where the first applications of AM in transportation were in the production of form fit and function prototypes used in the product development phase. Following on from this initial use, AM began to be used in the development of custom components for high-specification cars, such as racing cars, and prototype components for production vehicles. Often parts developed for transportation are of superior performance to conventionally manufactured counterparts where, for example, heat exchangers can be optimised for thermal transport and/or packaging, structural components can be optimised for weight or strength and cabin components can be customized to individual customer specifications. AM allows the shortening of supply chains and the manufacturer of legacy components which are out of stock. It improves design freedom conferring

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performance and mass customization advantages whilst allowing optimisation that was not possible using conventional manufacturing technologies. It also allows the reduction of the part count because of the ability of AM to integrate piece parts by concatenation.

Whilst AM has not gained a significant foothold in transportation for more volume production it is currently the subject of much research including the development of AM-produced batteries for electric vehicles, high-performance electric powertrain components and composites including tooling and materials.

> The energy sector has seen particular interest in the directed energy deposition (DED) methodologies

There are many barriers to the adoption of AM in transportation including cost, rate of production and the size of components. This is being addressed by several newer technologies including but not limited to multi-jet fusion and reactive material jetting. It should also be noted that the use of AM in transportation is risky because of the lack of significant amounts of added value from using AM. For example, it can be used for prototyping, customisation and lightweighting, but the value proposition is small, the costs are high and the production rate is low and hence there is a limited pull through from OEMs to have significant uptake and impact for more volume-based production.

AM in Energy

The energy sector was slow to take AM as a production or prototyping methodology because of issues regarding the materials produced in the processes and the size of components that it is possible to produce by AM. Recently, however, the appearance of metallic AM processes and the ability to produce materials in standard high-performance alloys has led to increased interest in the sector. In particular, AM is used in the energy sector to produce rotors, stators, turbine nozzles, down hole tool components, manifolds, and control valve/metering component parts. AM is also used for the manufacture of models for testing designs in laboratory facilities including fluid flow analysis.

Success in the energy sector hinges on the ability to quickly develop components that can withstand extreme conditions of temperature pressure and multiphase fluid flow. The ability of AM to provide rapid and high-performance components without the need for a considerable stock will is also a key driver for AM's application within the energy field.

The energy sector has seen particular interest in the directed energy deposition (DED) methodologies, where large near-net-shape free-form components can be made in metal for subsequent CNC machining.

The development of advanced alloys particularly corrosion and wear-resistance materials is of significant importance in the energy sector. Similarly, the development of alloys that can be utilised in radiation-affected zones such as nuclear fusion systems may provide a considerable application for metal-based additive manufacturing.

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The high cost of additive manufacturing is not necessarily a significant disadvantage in the energy sector. Of more importance is the size scalability of the processes currently available.

AM in Consumer Products

The main applications for AM in consumer products are simulating the look and feel of the final product ensuring that aesthetics and ergonomics are correct for design reviews and accelerating design iterations. Sporting goods have benefited from early iterations, entertainment props and costumes can be made very realistically at a fraction of the cost of employing modelmakers and prop artists. In architecture, finely detailed models can be produced communicating space and structural design. As 3D printing technology has advanced, the production of consumer products has started with the manufacturing of tooling for plastic injection moulding where cooling channels can be added to the tool, allowing for significant reductions in cycle time and improvement in production rate. Here a major disadvantage of metal AM is overcome by integrating AM tool production with more standard CNC tool shop operations such as CNC machining and spark-erosion.

> Cost barriers will reduce and more standard materials will be developed

There are three main advantages to the use of AM in the manufacture of consumer products, the ability to link directly to the virtual design environment, speed in the production of prototypes, the development of cooling control for tooling and the ability to manufacture short-run parts for products to test prototypes.

AM has been used to produce production intent consumer parts such a decorative goods, for example lampshades and art and in the sporting goods sector where the unique ability of AM to produce customised fit and specific dynamic properties via geometric structuring has enabled the manufacture of both high performance and consumer training shoes.

It is clear that as AM develops it is likely that we will see increased deployment in this area, cost barriers will reduce and more standard materials will be developed, both of which will enable the increased use of AM in this large sector. Cost, pace and deployable materials remain the main barriers to the adoption of AM in consumer products but these will likely become less of an issue as the technology develops over the next decade.

The Global AM Industry

AM is not entirely unique in its material addition methodology, being preceded by many other technologies that include this approach, for example, thermal spraying of metals and the fabrication of electronic components, which all include a material addition step as part of their processing methodology. However, in AM – all driven from a digital 3D model – the whole or the vast majority of a part is produced by adding material, automatically producing complex, functional and detailed parts without considerable human intervention. AM's ability to fabricate components in this manner, which principally enables significantly increased design complexity, has made it very attractive to many industries with diverse applications being researched and commercialised over the years.

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AM has grown significantly over the last 35 years and was valued at €7.17 billion in 2020, €8.33 in 2021 (CAGR of 16.2%) with a predicted growth to €19.23 billion by 2026 (CAGR of 18.2%) (AM Power, 2022) with the largest markets being in the USA and China. In 2020, the medical industry (for example, dental aligners, hearing aids, bone replacement endoprosthesis, or components based on CT scan data, etc) was the predominant area for AM system suppliers', generating a large share of the total system sales revenue. A multitude of different metal and polymer AM technologies are used in industry today. In 2020 Powder Bed Fusion had the largest share of the market, with over 50 % of the global sales revenue. In metal AM, powder-bed based "bind and sinter" technologies are also gaining traction as highly productive alternatives and are expected to increase their impact significantly in the next five years. Polymer technologies will continue to be dominated by Stereolithography which will continue to increase its revenue share and SLS and MJF will maintain their position because of their abilities to manufacture production intent materials with no supports at high rates (AM Power, 2022). Filament based technologies will continue to be developed with significant innovation being supplied by the huge install base of hobbyist developers, small companies making bespoke solutions and enterprises pushing the envelope of machine performance and size.

Figure 1 AM Share Prices Compared, 3D Systems (Black), Stratasys (Blue) and Materialise (Orange) and Desktop Metal (Purple)

AM's unique attractiveness, the pace of R&D development and a myriad of available technologies has led to turbulent valuations for AM companies. If the % change in share price of 3D Systems (DDD), Stratasys (SSYS), Materialise (MATL) and Desktop Metal (DM) are tracked from the late 90s using Barchart.com (whilst noting the differences in time when the companies were first quoted), it is clear that share prices show considerable volatility. Figure 1 shows that there is a steady growth of 3D Systems and Stratasys share price between the mid-'90s and late 2007, however, in 2008 the global downturn brought a significant fall in share price wiping around a third off both 3D Systems and Stratasys' valuation.

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From this low point, share prices boomed, mainly fuelled by the open-source 3D printer bubble that was preceded by the lapse of Stratasys FDM patents with share prices peaking in December 2013 (December 2013 share prices DDD $92.93 a 3995% gain on initial price, SSYS $134.7 a 4602% gain on initial price). From this point, share prices tumbles until early 2016 when some stability was regained at a rather less enthusiastic level. Whilst both 3D Systems (249% gain on initial price) and Stratasys (469% gain on initial price) were still showing profits for their initial investors this considerable decrease in sentiment shows a substantial reduction in value from the peak just 24 months earlier.

Between early 2016 and October 2020 the % change on initial value reduced at a lower rate with 3D Systems showing a 148% gain on the initial price and Stratasys a 346% gain on the initial price. At this point Materialise, after several years of marginal share price growth, demonstrated a 195% gain on the initial offering – though it should be noted that the characteristic curve for Materialise is much less volatile, possibly because of the emphasis on software rather than large capital equipment sales. Early 2021

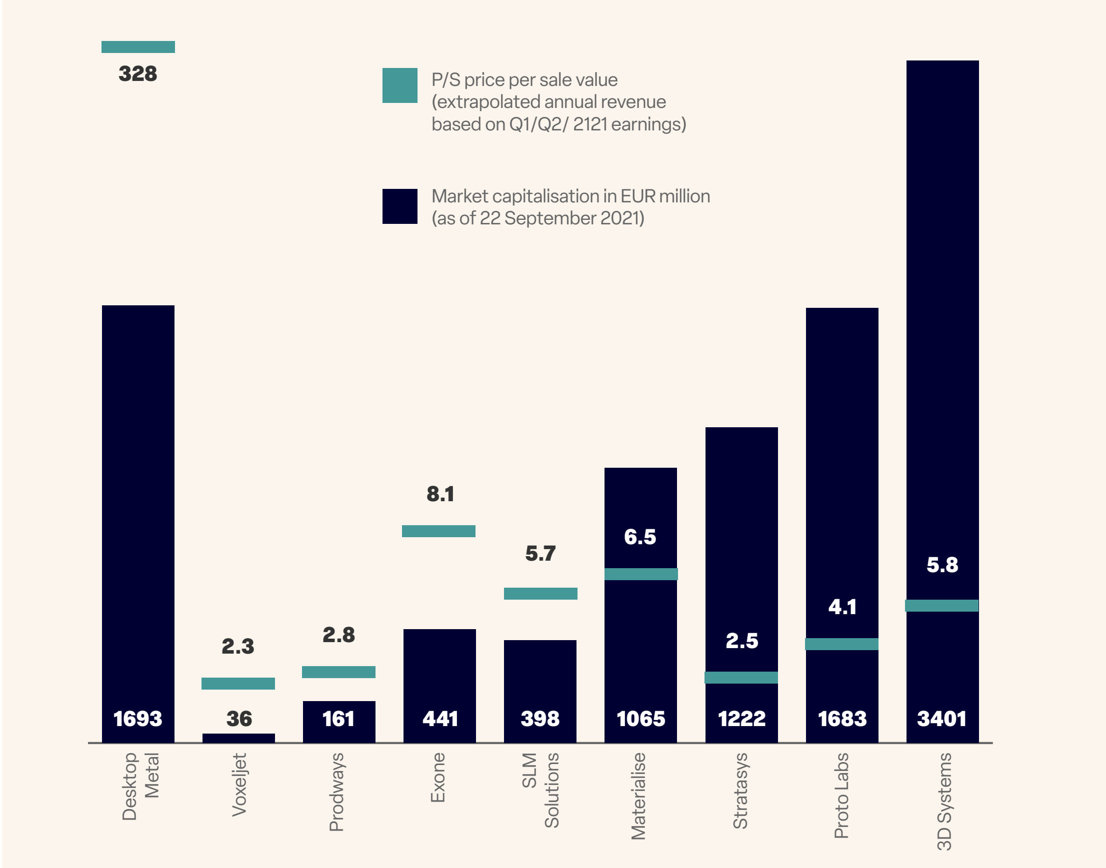

Figure 2 P/S Price Per Sale Value of Nine Highly Ranked AM Companies

once again saw a boom for investors in the four tracked companies with Desktop Metal showing a 130% gain in January 2021, however, since this point, all of the tracked companies' share value has fallen considerably with current values being 3D Systems 244% gain, Stratasys 390% gain,

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Materialise 7% loss and Desktop Metal 76% loss. It should not be forgotten that, although both 3D Systems and Stratasys are long-established companies, these current prices do not compare well to the heyday of their activity where gains were on or around 4000%.

Figure 2 (taken from: (Munsch, Schmidt-Lehr, & Wycisk, 2021)) indicates the P/S ratio for nine quoted AM companies. The P/S ratio is an investment valuation ratio that shows a company's market capitalization divided by the company's sales for the previous 12 months. It is a measure of the value investors are receiving from a company's stock by indicating how much equity is required to deliver $1 of revenue. Analysts prefer to see a lower number for the ratio generally in the range of 1 < P/S < 5. Figure 2 shows that P/S metrics for traded AM companies are high and, in some cases, extremely high. This either indicates a market with strong investor growth expectations or a sector that is overhyped with companies that are overmarketed. The overhyped/marketed argument is illustrated by the "old hand" companies such as Stratasys, Proto Labs and 3D Systems, all of whom have P/S on or around the normally accepted 1-5 range. Desktop Metal seems to be the strongest outlier in this data with a P/E of over 300 – two orders of magnitude over the accepted mean for P/S.

Table 2 ▼ UK Global Position as a Manufacturing Nation (Make UK, 2022)

Global position	9th largest globally
Output generated by manufacturing	£183 Billion
People Employed	2.5 Million
Contribution to the UK economy	11%
Contribution to UK exports	51%
Contribution to UK business R&D	64%
UK business investment	15% of total
Wages	12% higher than the average (£35,277 pa)

The volatility in company value combined with P/S metrics illustrates that considerable care must be taken when investing in AM. The AM market is volatile, prone to high expectations, overstatement and rapid changes in technology from R&D effort. Due to many factors, depending on the particular AM approach / material adopted, It also has struggled over the years to find strong footholds in mass production with only a few sectors embracing the technologies offered as appropriate as their final production process. Considerable further R&D Investment is usually required before AM approaches gain the acceptance required for it to become a standard manufacturing technology – this is beginning to happen for some processes / materials and in some sectors where sustained effort has been expended, but is far from universal or transferable to all industrial sectors / applications. That said several new technologies show promise, for

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example the work by Seurat Technologies, Vulcan Forms, several more standard Laser and Electron Beam companies and the many Binder Jet Fusion-based technologies that are seeking to move AM to production.

Additive Manufacturing in the UK

There are many reports on the health of UK manufacturing in general, with a typically quoted position for 2022 given in Table 2 below (Make UK, 2022). It is clear that the manufacturing sector is an important contributor to the UK's economy and although the UK's present position has declined since the 1970's, the UK remains a key global manufacturing player ranking in the top 10 in the world in terms of output.

Though the sector has also undergone some significant changes, the UK remains a global player – predominantly within high-value manufacturing sectors, such as medical devices, aerospace and some aspects of automotive. In terms of AM, though the UK has been a world leader in researching and developing technology, it is only home to two key primary technology developers: Renishaw who manufacture laser-based Powder Bed Fusion Machines and Wayland Additive, who manufacture Electron Beam Powder Bed Fusion systems. Similarly, the UK has pioneered applications for commercialisation, as exemplified by the development of porous orthopaedic structures at the University of Liverpool. However, there has been very little activity in terms of large-scale manufacturing using AM in the UK where, for example, the porous implant technology developed at Liverpool is now the key technology used in the Stryker facility in Cork, Ireland.

In 2014 a group of industry experts formed "AMUK", an independent, government-supported collaboration that led extensive, UK-wide consultations and workshops. This group finally produced, with the engagement of a further 100 experts working in seven cross-sector, thematic working groups, a national strategy for AM in the UK.

> Though the sector has also undergone some significant changes, the UK remains a global player

This strategy was published in late 2017 with amendments in late 2018 (Additive Manufacturing UK, 2017).

The final UK Strategy document indicated that the total opportunity for AM was £3,500M GVA and 60,000 jobs by 2025 and made many recommendations as to how this opportunity might be realised and is summarised with corresponding comments from this report's authors in Table 3 below:

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AMUK Recommendation Group 1: Cross-Cutting Activities		
	Recommendation	**This report's Authors' comments on progress**
1.1	Develop awareness of AM and dispel myths and hype by a collaborative campaign	There has been no collaborative campaign.
1.2	Tighten the operational linkages between AM and Industrial Digitisation	This seems to be an Operational issue for iUK Catapult and as such should be completed as a matter of course.

AMUK Recommendation Group 2: Design Activities		
	Recommendation	**This report's Authors' comments on progress**
2.1	Commission a study on AM design guides corralling them and making a free online portal	No specific 'AM design portal' exists; there are many online or otherwise design guides and this should be made part of the AMUK website.
2.2	Run an R&D programme on design for AM	There are now many tools for DfAM available commercially. At least three of these have been developed in the UK, two of which have been sold to software houses. Whilst this is a laudable recommendation, any future R&D spend in this area should significantly go beyond the state of the art.

▼ Table 3 Continued

Table 3 ▼ AMUK Report Recommendations

AMUK Recommendation Group 3: Materials and Processes Activities		
	Recommendation	**This report's Authors' comments on progress**
3.1	Develop a series of AM case studies	All case study recommendations should be compressed into one activity and draw heavily on studies that already exist and contain interactive and numeric data.
3.2	Fund R&D activity on online education tools	There are many courses and modules in AM supplied either by companies or educational establishments. As such, there is no need for high levels of funding in this area and any funding should draw upon the education aspects of already published qualifications.
3.3	Support R&D to develop equipment for productivity, stability, machining and materials supply	Whilst there are many R&D projects on AM, very few develop equipment – indeed, this is the Achilles heel for AM in the UK where we do not historically develop home-grown technologies. Any R&D funding in this area should specifically call on the development of new and exciting technologies for productionisation.
3.4	Support R&D to optimise AM production including post-processing	This recommendation goes hand in hand with recommendation 3. Optimisation of AM for production is the role of industry but can only be achieved if high production rate equipment exists.
3.5	Continue and increase funding of new materials designed for AM	There is scope in specifically developing AM materials, however this enthusiasm must be tempered by some concentration on standard production materials. Scalmalloy (Airbus) and A20X (Aeromet) are two good examples of materials developed for AM. There is a significant need for production intent polymers that can be produced at rate.

▼ Table 3 Continued

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Table 3 ▼ AMUK Report Recommendations

AMUK Recommendation Group 4 Inspections Test and Standards Activities		
	Recommendation	**This report's Authors' comments on progress**
4.1	Implement a co-ordinated and ongoing additive manufacturing standards development	Standards development is already underway by the relevant BSi, ISO and ASTM authorities in collaboration with many AM players.
4.2	Develop and share Non-Destructive Testing (NDT) and mechanical testing processes	It is perhaps unrealistic to expect a company to develop NDT and mechanical testing methodologies for the development of their products and then share them.
4.3	Develop and maintain an accessible AM material properties and standards database	Granta design has an AM materials database, the Additive Manufacturing Materials Database (AMMD) is available through NIST and Senvol has a comprehensive database for industrial AM. It is suggested that there is not a requirement for another one.

AMUK Recommendation Group 5 Skills and Education Activities		
	Recommendation	**This report's Authors' comments on progress**
5.1	Develop skills packages (vocational and apprenticeships) for the current and future workforce	AM is a specialism, much like Injection Moulding or CNC Machining both of which have modules within the required vocational qualifications. There is certainly a need for specific AM modules to run alongside these other manufacturing methods but the need for specific AM Apprentices/Vocational qualifications is perhaps questionable at this time.
5.2	Expand the existing KTN AM SIG activity to continue to build the AM community	This is currently underway with the relaunch of AMUK including the use of a powerful supply chain mapping tool.
5.3	Create and run an AM awareness campaign to help firms accelerate industrial exploitation	Being now more of an "emerged" rather than "emerging" technology, industry is already becoming very aware of AM, in particular through the recruitment of recently graduated cohorts of students. If this recommendation is to be implemented, more creative methods of increasing engagement / implementation is required rather than awareness.

▼ Table 3 Continued

Table 3 ▼ AMUK Report Recommendations

AMUK Recommendation Group 6: Supply Chain Activities		
	Recommendation	**This report's Authors' comments on progress**
6.1	Produce a comprehensive map of the UK additive manufacturing supply chain capability and capacity to be produced. Determine gaps and UK strategic priorities. Fund a programme of various activities to address the strategic weaknesses.	AMUK has recently partnered with Value Chain a state-of-the-art supply chain mapping software. This activity should be accelerated and improved.
6.2	Commission and maintain an online map of UK additive manufacturing supply-chain capability and capacity. Determine gaps and fund a programme to address strategic weaknesses.	See 6.1 above.
6.3	Drawing upon a UK additive manufacturing supply chain mapping exercise, the programme would also cover other value chain elements such as finish machining and materials supply.	See 6.1 and 6.2 above.
6.4	Extend the Catapult 'Reach' programme targeting SMEs	It is suggested that the success of the 'Reach' programme is firstly independently reviewed to analyse its efficiency and effectiveness before any further funding is made available. We also suggest that this funding is extended to universities and other TROs in competition with the Catapults to encourage and engage SMEs in fundamental-level R&D.

▼ Table 3 Continued

Table 3 ▼ AMUK Report Recommendations

AMUK Recommendation Group 7: Commercial, Intellectual Property and Data Management Activities		
	Recommendation	**This report's Authors' comments on progress**
7.1	Run co-ordinated exercises to identify additive manufacturing-specific and digital manufacturing-related IP issues (including licencing, payment methods, design and collaboration). Set out a collaborative work programme to address the issues identified, highlighting roles and responsibilities.	Currently, the Catapult network has very limited IP activity judging by their lack of patented inventions; it is therefore unclear why and how this could be implemented successfully. Potentially the richest resource for this activity lies within university commercialisation departments, of which there are several successful examples in the AM space.
7.2	Implement an additive manufacturing-related product liability definition and collaborative action programme.	This is mainly a standards-based activity. However, it is also challenging to identify any significant difference between the liability requirements placed on an AM part compared to a part manufactured by conventional means. For example, medical devices manufactured by AM do not have a different liability compared to other implants.
7.3	Commission and publish case studies of the economics of additive manufacturing and different additive manufacturing-related business models, to provide evidence to help the finance community make investments to enable firms of all sizes to adopt additive manufacturing. This aims to make additive manufacturing with better understood in the financial community, resulting in more funding for adoption of additive manufacturing by business	This activity should be part and parcel of the other case study activities. All case studies should have details on the business and financial models used to make them a success.

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▼ Table 3 Continued

Table 3 ▼ AMUK Report Recommendations

AMUK Recommendation Group 8: AMUK Implementation Activities		
	Recommendation	**This report's Authors' comments on progress**
8.1	Develop links to all aspects of the digital space, connecting with relevant supply chain review activity and follow through any recommendations in both the digital and real world.	It is not clear what this recommendation means.
8.2	Clarify digital manufacturing-related licencing, payment methods, design, and collaboration. Set out a collaborative work programme to action issues.	It is not clear what this recommendation means.
8.3	Implement Phase 2 investment in the National Centre for Additive Manufacturing, developing it through a hub and spoke model.	This should be independently reviewed for its efficiency and effectiveness against a set of metrics prior to any further funding.
8.4	Support the development of an expert UK additive manufacturing User Group, similar to the successful USA model.	Suggest that this links with the already established conferences like TCT and Nottingham conference.
8.5	Establish and run a national help and contact point organisation	Most likely an AMUK activity, due to its links to the supply chain.

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01. INTRODUCTION

The AMUK group was re-established recently (1st October 2022) and it remains to be seen if this group now run in partnership with the Manufacturing Technologies Association (MTA) will make inroads into their list of recommendations, however it is clear from the comments in Table 3 that many of the recommendations have either, expired during hiatus of AMUK, are vague, or already exist either commercially through products or freely available online. Of the tasks that remain only a few stand out that require urgent action including 3.3, 3.4, 3.5, 4.1, 4.2, 5.1 (In part) and 6.4 (needs to be carefully considered).

Data Collection Methods

To simplify the process of collecting data the authors decided from the outset that all projects whose description contains d particular keywords, such as "Additive Manufacturing" or "3D Printing" would be included in the review. This is in contrast to previous reports and allows the "capture" of all projects funded in the UK and avoids the need to analyse the specific aims of each project in detail. Each project received funding from a non-commercial source and involved at least one element of research relating to advancing the field of additive manufacturing.

Funding Data

Research project data was retrieved from the United Kingdom Research and Innovation (UKRI) database of funded projects (https://gtr.ukri.org/) using the search term "Additive Manufacturing" or "3D Printing" in "Project Abstract" or "Project Title". Data was triaged to projects funded between 30/06/2010 and 30/06/2020 as the authors wanted to capture "new" project that are relevant to Additive Manufacturing and not earlier Rapid Prototyping. The reason for the cut-off date of 30/06/2022 is that it was considered that projects funded after this date would not have created tangible impacts at the time of writing this report.

Publication Data

Research publication data was retrieved using Elsevier's SciVal tool linked to the Scopus database. This is an abstract and citation database of peer-reviewed literature including scientific journals, books, and conference proceedings and provides a comprehensive overview of worldwide research output in science, technology, medicine, social sciences, and arts and humanities. The data set generated was for the top 500 authors, by Scholarly Output in AM or 3D printing, between 2012 to 2021 across all publication types and including self-citations.

Patent Data

Patent data was collected from Espacenet, The European Patent Office's (EPO's) database of patents containing data on more than 130 million global patents using various search terms and filters described in the results section.

Spin Out Company Data

Further data was collected from Crunchbase, pertinent company websites and reports optimised from knowledge of the market, concentrating particularly on companies that have spun out of government-funded programmes.

References

References are given throughout the text to aid the reader and in addition, this report uses the following reports as a references: (List & Tietze, 2017), (Li, Myant, & Wu, 2016) and (Reeves, Jones, & Hague, 2016).

02. RESULTS AND DISCUSSION

The following results with included discussion were derived from this work.

UK Research Funding Levels

Using the search term “Additive Manufacturing” and/or “3D Printing” in “Project Abstract” or “Project Title” in the publicly available UKRI data between 30/06/2010 and 30/06/2020 resulted in the following data shown in Table 4:

Table 4 ▼ UKRi Project Funding 2010-2020

Total Funding	£358,973,056
Total Projects	509
Total Studentships (non-CDT)	296

The total research funding for AM-related research was £358,973,056. This is a significant amount considering the niche manufacturing technology that AM is and perhaps reflects some of the hype surrounding the field between the dates surveyed (particularly 2012-2014). The year-by-year analysis shown in Figure 3 indicates that research funding slowed in 2019 and 2020, potentially due in part to the change in priorities forced on funding bodies because of the pandemic.

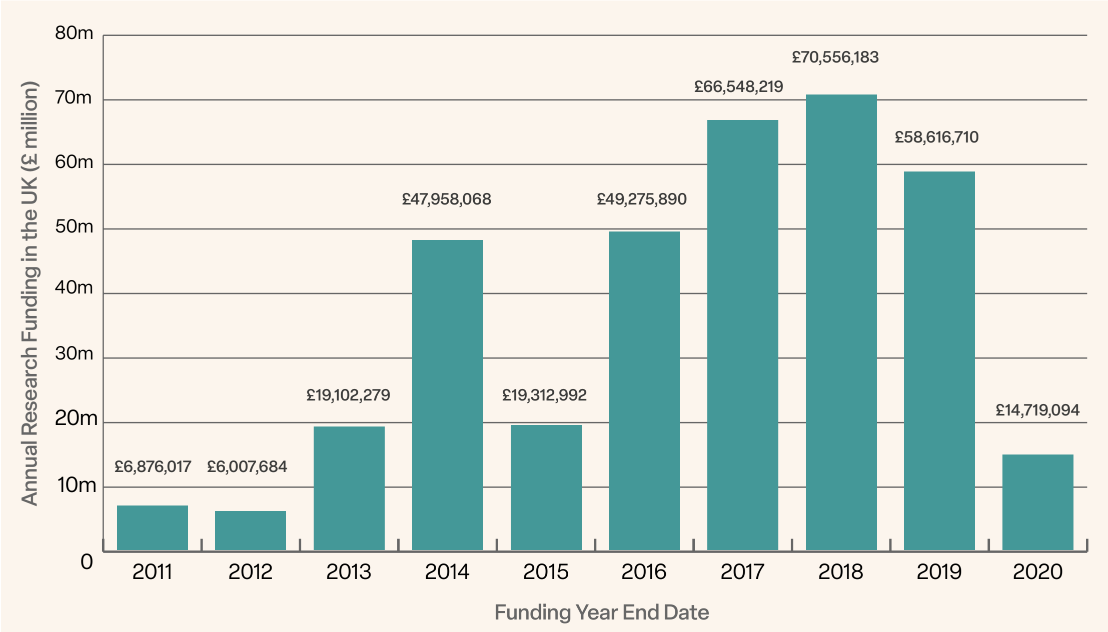

Figure 3 UK AM Research Funding 2010-2020

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Non-CDT (PhD level Centre for Doctoral Training) student funding across UK Universities also showed a year by year increase, except for 2020, as shown in Figure 4. In total 296 non-CDT studentships were funded during the period. Yearly funded amounts in both cash and studentship terms were considered healthy but the reduction in funding following the pandemic is concerning.

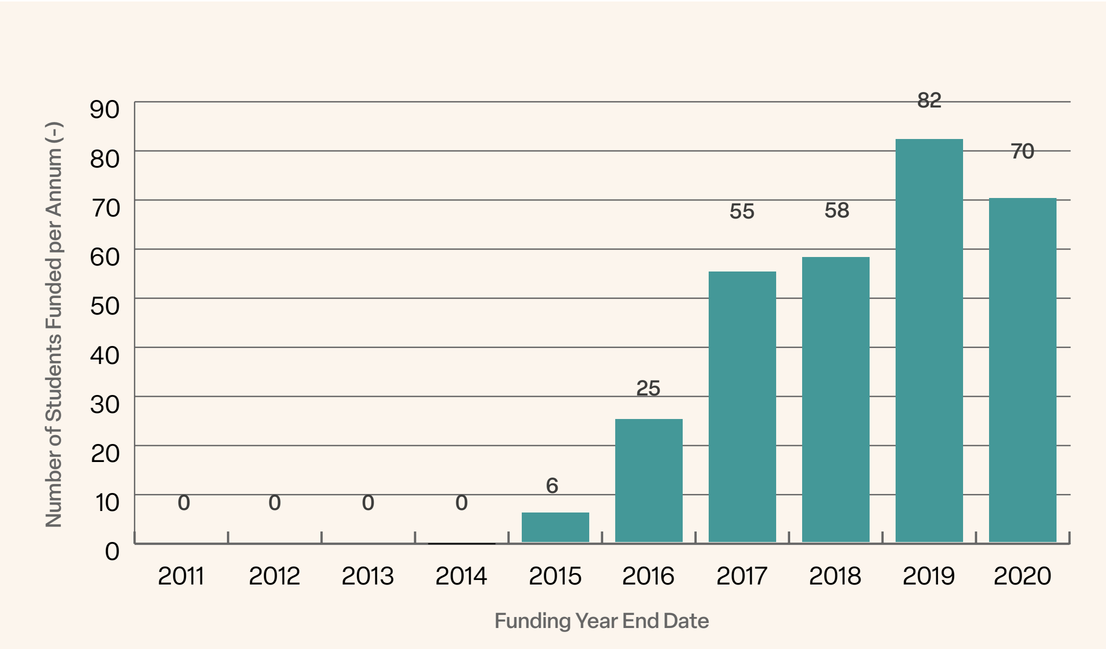

Figure 4 UK AM Research Studentships 2010-2020

UK AM Research Funding Geographic Distribution

Taking a more granular look at the overall funding landscape, it is possible to break this down further in to regional funding, as shown in Table 5 below and Figure 5 below:

Table 5 ▼ Over/Underspend per Region

Region	UKRI Additive Spend in Region	Regional Manufacturing Jobs (1,000s)	% Regional Manufacturing Jobs	UKRI Additive Spend per Regional Manufacturing Job	Over/Underspend per Regional Manufacturing Job %
London	£35,455,325.00	132	5%	£268.60	225%
East Midlands	£64,157,732.00	297	11%	£216.02	181%
East of England	£42,731,311.00	231	9%	£184.98	155%
South East	£55,168,868.00	299	11%	£184.51	155%
South West	£40,340,115.00	243	9%	£166.01	139%
Yorkshire and The Humber	£36,971,564.00	290	11%	£127.49	107%
Scotland	£20,770,924.00	191	7%	£108.75	91%
West Midlands	£30,921,168.00	317	12%	£97.54	82%
North West	£19,130,712.00	345	13%	£55.45	47%
Northern Ireland	£4,070,174.00	96	4%	£42.40	36%
North East	£4,420,620.00	120	4%	£36.84	31%
Wales	£4,834,543.00	155	6%	£31.19	26%
Totals	**£323,517,731.00**	**2716**	**100%**	**£119.12**	

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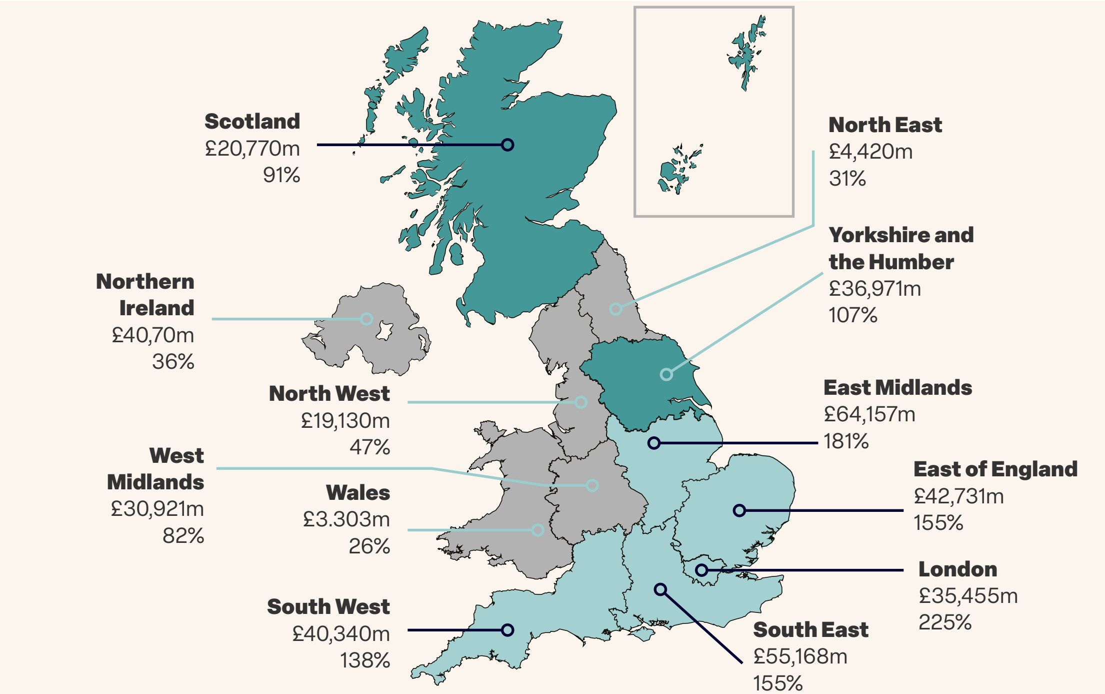

Figure 5 Regional Distribution of Research Funding 2010-2022

The data in Table 5 were normalised by the regional number of manufacturing jobs, as taken from ONS data, to reveal regions with the most funding per head in relation to manufacturing jobs in those regions. The data shows that a clear regional divide exists between those areas that are well-funded and those which are not, which is graphically shown and colour coded in Figure 5.

If we include data from the amber areas (i.e. those which are within 10% of the average funding per manufacturing job) then the difference is stark.

The average funding of the well-funded areas of London, East Midlands, East of England the South East and the South West garner on average 171% funding per manufacturing jobs whilst the underfunded/averagely funded areas of Yorkshire and The Humber, Scotland, West Midlands, North West, Northern Ireland, North East and Wales garner only 60%. The map shows a clear North-South divide and whilst this data could be considered to be skewed somewhat by the registration of companies in London as opposed to where they operate, this isn't the case for the universities. Similarly, one could argue that several large university AM research centres exist which may similarly skew the data, this is particularly true for The University of Nottingham in the East Midlands. However, several large and successful AM university research groups also exist in the underfunded regions including Sheffield, in Yorkshire and the Humber, and Liverpool and Manchester, in the North West.

UK AM Research Funding Lead Partner Type

Further analysis of the data looking at the split of funding between universities and industry / RTOs reveals the data shown in Figure 6. These data show that there is a roughly 50:50 division between projects led by universities and industry/ RTOs.

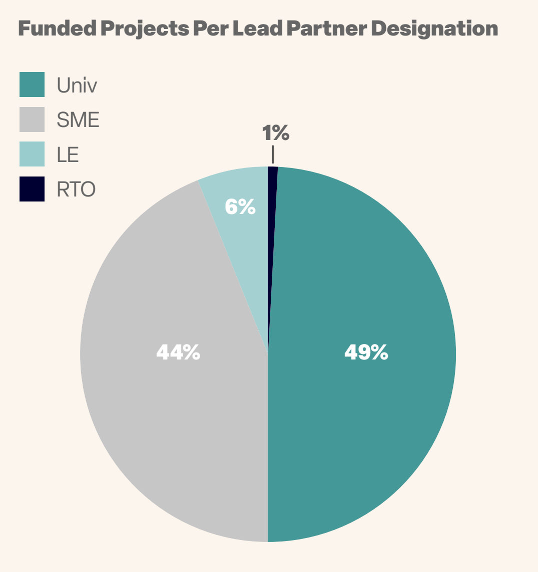

Figure 6 Number of Funded Projects Per Lead Partner Enterprise Designation

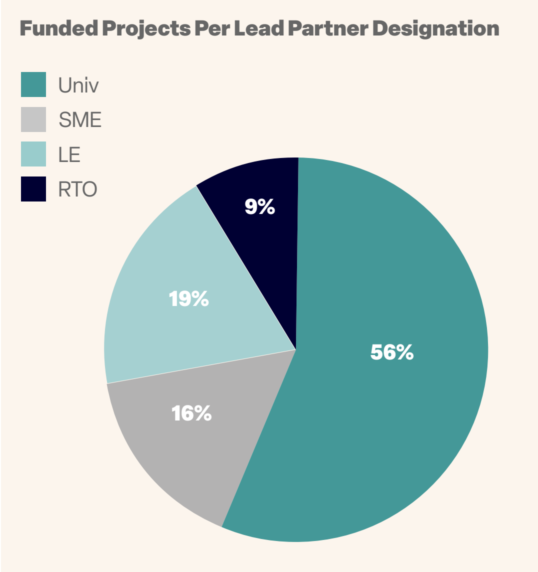

Figure 7 Funded Amount Per Lead Partner Enterprise Designation

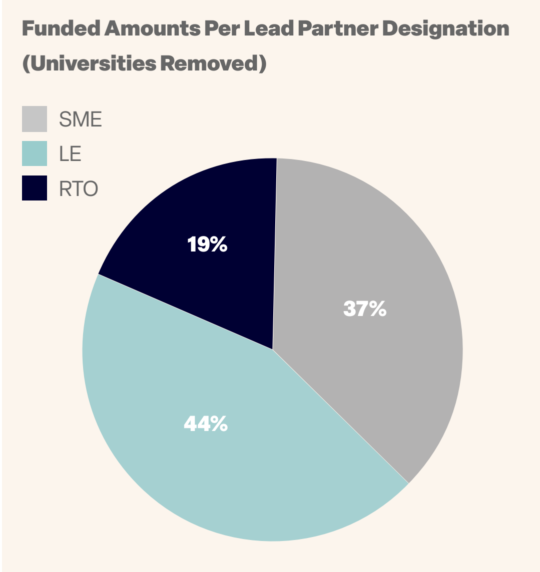

Figure 8 Funded Amount Per Lead Partner Designation (Ignoring Universities)

This is actually understandable because whilst universities lead awards from the research councils, they cannot lead iUK grant applications. At 1% the number of RTO-led projects is particularly small; however, it is important to remember that RTOs tend not to lead projects. It is also challenging to gauge the funds received by RTOs as non-lead partners from the UKRi data set.

Calculating the actual funds that are granted to each enterprise designation results in the data shown in Figure 7. This data shows that there is a slight uplift in funding going to universities with the split being 56:44 in favour of universities as opposed to industry / RTOs.

Removing universities from the analysis reveals Figure 8, which shows that the 1% of the total projects funded at RTOs tend to be large value and represent 19% of the total funding granted to non-university entities.

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02. RESULTS AND DISCUSSION

Overall analysis of university funding in the period showed that 27 UK universities garnered over £1M of funding in the period. The top 20 universities are shown in Table 6.

The most successful universities in terms of receiving funding were Nottingham, Sheffield and Cambridge each winning over £20M in funding. Each of these universities has large and active research groups in AM, has or had CDTs in AM or related topics and have a long history of working in AM. As such, this is perhaps unsurprising. However, what should perhaps be noted is the appearance of many universities receiving high levels of funding that are not particularly well known (in terms of outputs) for their research in AM. This is potentially a function of the search criteria used and the tendency for academics to populate their research grant applications with the latest technologies, for example, "Additive Manufacturing" and "3D Printing" are/were areas that either the funding bodies required the academics to propose research or were/are buzz words that are likely to score highly at review.

Table 6 ▼ UK Top 20 Funded Universities

University of Nottingham	£	29,949,527
University of Sheffield	£	24,383,830
University of Cambridge	£	23,601,568
Imperial College London	£	18,708,719
Loughborough University	£	12,192,375
University of Bristol	£	10,330,025
University of Manchester	£	9,262,990
University of Strathclyde	£	6,754,507
Cranfield University	£	6,578,098
University of Glasgow	£	5,783,757
University of Birmingham	£	5,284,594
University College London	£	4,854,364
University of St Andrews	£	4,040,795
University of Bath	£	3,875,561
University of Southampton	£	3,840,778
Queen's University of Belfast	£	3,604,056
University of Kent	£	2,911,822
University of the West of England	£	2,182,015
University of Liverpool	£	2,139,983
Heriot-Watt University	£	2,117,746

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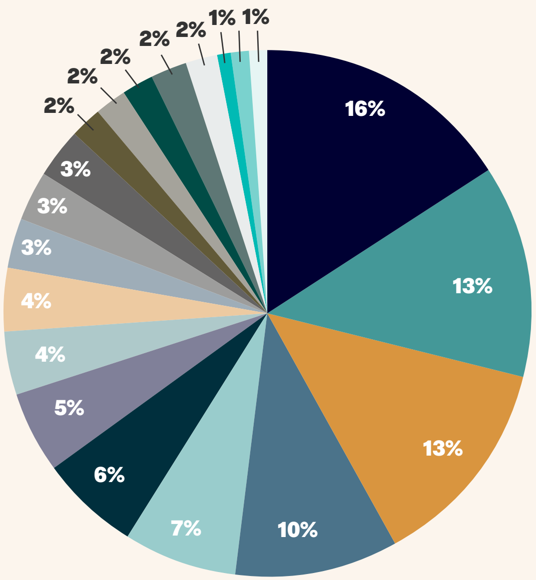
02. RESULTS AND DISCUSSION

It is clear from knowledge of the area that many of these universities in the top 20 funded classification do not have a considerable pedigree in delivering AM innovations, though they may have skills in other areas that can utilise AM and indeed develop applications of AM. As such, they may be considered to be users of AM, but they are not considered to be key players within the AM process or equipment development field. This is illustrated by the relatively poor performance of Cranfield and Liverpool in this table which, considering their key performance in developing equipment and process IP ranking 9th and 19th in the table respectively.

It should also be noted that Loughborough and Nottingham are essentially the same research group as many of the key players (Hague, Tuck, Wildman and Dickens) moved from Loughborough to Nottingham in 2012 with Loughborough receiving limited research funds from this point on. This data is graphically shown in Figure 9 to allow some perspective on the funding amounts at each university.

Top 20 Funded UK Universities in AM/3D Printing as Lead Partner



	University of Nottingham	£299,495,27
	University of Sheffield	£243,838,30
	University of Cambridge	£236,015,68
	Imperial College London	£187,078,19
	Loughborough University	£121,923,75
	University of Bristol	£103,300,25
	University of Manchester	£926,299,0
	University of Strathclyde	£675,45,07
	Cranfield University	£657,80,98
	University of Glasgow	£578,37,57
	University of Birmingham	£528,45,94
	University College London	£485,43,64
	University of St Andrews	£40,407,95
	University of Bath	£38,755,61
	University of Southampton	£38,407,78
	Queen's University of Belfast	£36,040,56
	University of Kent	£29,118,22
	University of the West of England	£21,820,15
	University of Liverpool	£21,399,83
	Herriot-Watt University	£21,177,46

Figure 9 Top 20 Funded UK Universities in AM/3D Printing as Lead Partner

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UK AM Research Publications

Academic institutions have gained some 56% of the total UK funding and it is, therefore, relevant and interesting to look at the "who" and the "where" of the output metrics for universities. To do this Scopus searches were carried out using the search terms described previously. The results of this search allow an understanding of which authors at which institutions are publishing in AM. The data gathered was triaged manually to remove any non-UK authors and it should be noted that multi-authorship has not been considered and there are many cases of papers appearing multiple times in the analysis, which it is accepted may skew the data.

The publishing data shown in Figure 10 shows that the author with the most publications were made by Williams of Cranfield. This is an interesting outcome as Cranfield was only 9th on the funding list and yet has managed a substantial publication record. Of the next seven authors, six are from the University of Nottingham with the exception of Ding from Cranfield in 7th place. Seven of the top 20 authors are from the University of Nottingham. Other authors of note are: Todd from Sheffield citing considerable publication numbers

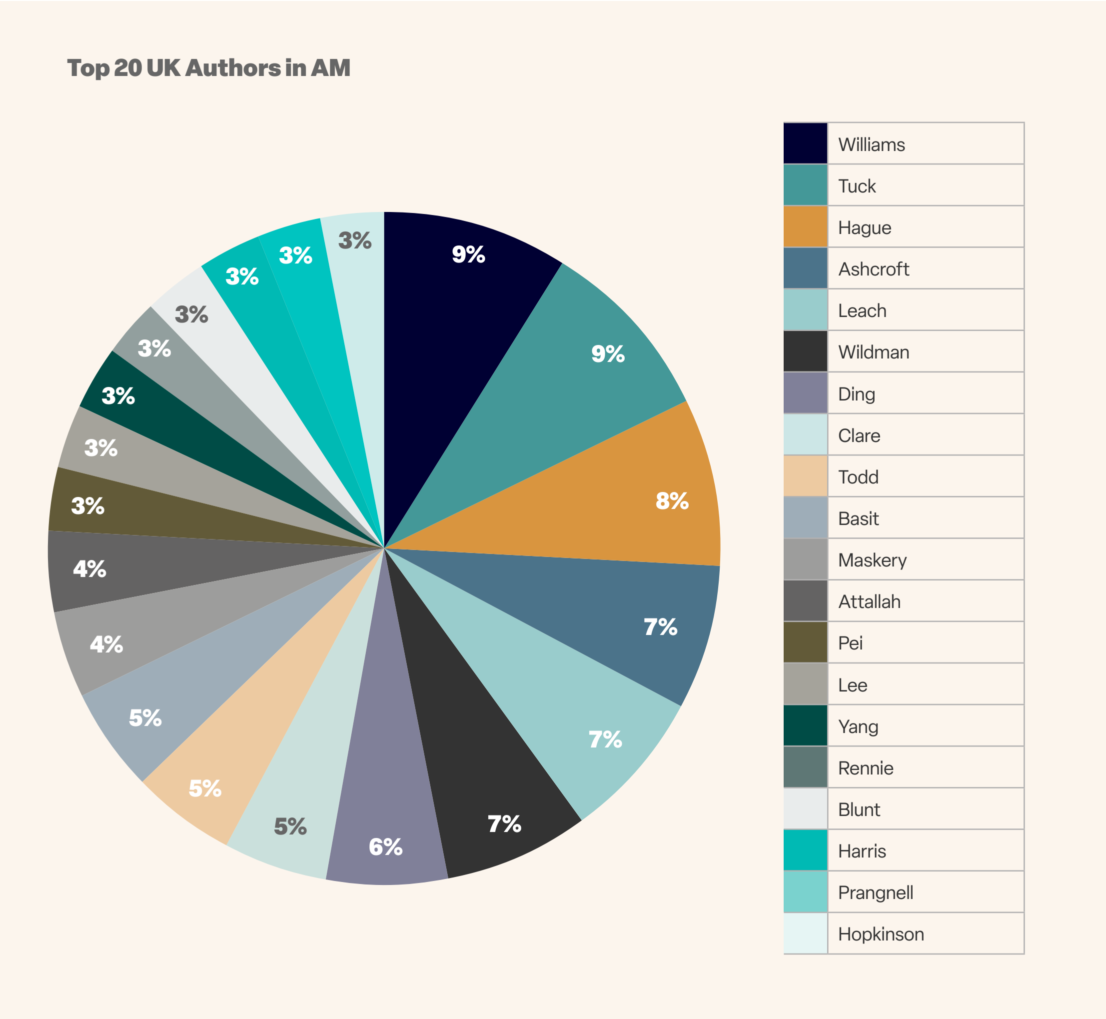

Figure 10 Top 20 UK Authors in AM

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in Materials Science and Metallurgy; Attallah from Birmingham, once again with a materials science cannon; and Lee (UCL / Imperial) with considerable work on in-situ measurements and CT scanning. The remaining authors are from Sheffield, UCL, Birmingham, Brunel, Southampton, Lancaster, Huddersfield, Leeds and Manchester. Liverpool whilst appearing in the Top 20 are publishing at a lower rate than might be expected, however, it should be noted that they are successful spinning out/ licensing their IP in Orthopaedics (both veterinary and human), machine design (MTT and Renishaw) and R-PBF (Meta additive, sold to desktop metal).

The top publishing Institutions can be seen in Figure 11 with The University of Nottingham at the top followed by Loughborough (once again with the caveat of group movement between these two institutions). This is followed by Sheffield and Cranfield whose performance is largely down to Williams' high publication rate.

Comparing research funding to publication track record indicates which universities are publishing more or less in comparison to their

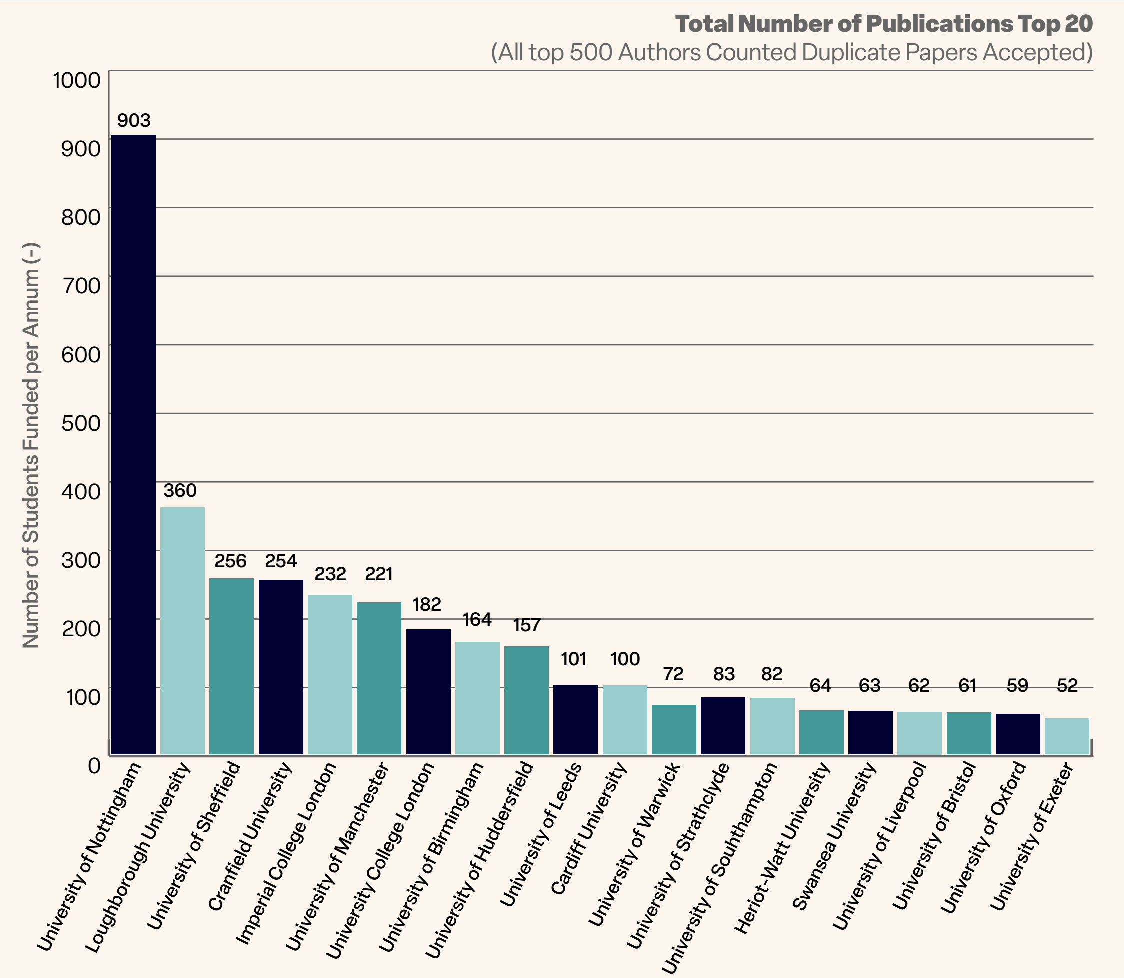

Figure 11 Top 20 UK AM Publishing Institutions

funding position. Top performing institutions are Cardiff (27 places higher in terms of publication from their funding position), Huddersfield (20 place improvement) and Warwick (13 place improvement). Poor performers are Imperial College London (1 place deficit), Strathclyde (5 place deficit) and Bristol (12 place deficit).

Research group size is difficult to estimate from the data sources available but if one considers the number of authors from a particular institution appearing in the Top 500 authors as a metric, then the data given in Table 7 gives a ranking of leading Universities.

Table 7 ▼ Number of Top 500 AM Authors by Institution

Institution	Number of Authors from this Institution
University of Nottingham	48
Loughborough University	27
Imperial College London	26
University of Manchester	20
University of Sheffield	18
University of Birmingham	15
University College London	14
Cranfield University	12
University of Huddersfield	12
Total Others	190

Figure 12 gives an overview of "publication value" by looking at the Top 20 UK institutions with the average cost per publication being shown by the horizontal line. "Expensive" institutions, or those that are underperforming in terms of publications, are shown in orange. The Mean cost of completing research to publication is £38k. Whilst this may seem to be a large investment it should be noted that it includes the FEC staffing and capital costs for the work. It is clear that some Institutions provide better value for money in terms of publication for their research spend, however, it should also be noted that differing types of research have different cost bases and that publications are not the only measure of research performance. Also, the data below does not indicate relative levels of publication quality. That said publication is the overriding concern for the majority of active research academics and therefore, whilst this simple metric could be misunderstood, it does serve to highlight where there may be problems of poor value.

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Research Cost Per Publication (Top 20 UK Publishing Institutions)

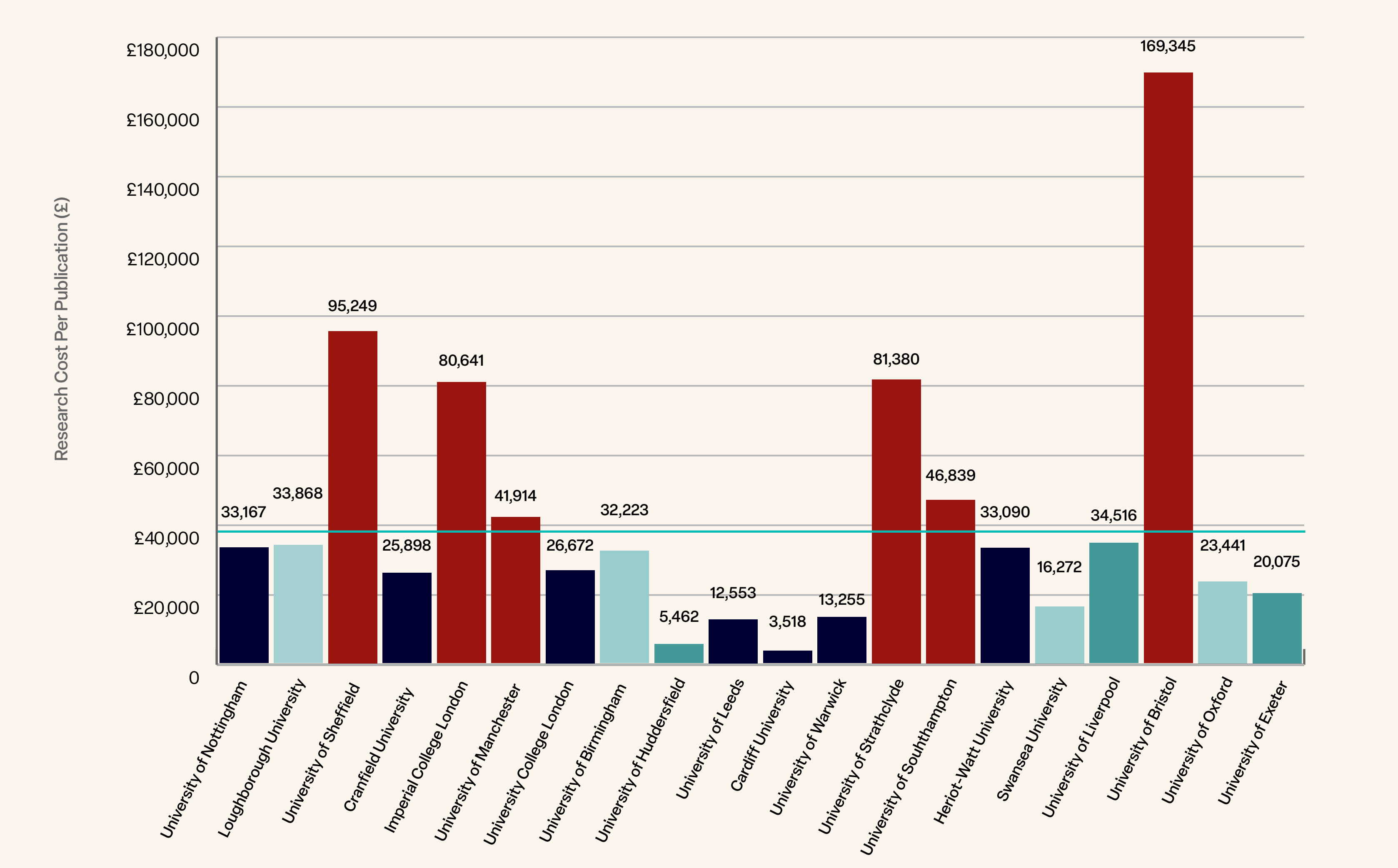

Figure 12 Research Cost Per Publication (Top 20 UK Publishing institutions)

UK AM Patent Landscape

The authors used the Espacenet database to collect and analyse data on published patents. Readers should note that no differentiation was made between awarded and pending patent applications as it was considered that simply applying for a patent was sufficient to demonstrate intent to protect and commercialise ideas. Generally, the terms "Additive Manufacturing" AND "3D Printing" were used. Patent searches were, in the most, constrained to patents with a first publication date of >= 2010. Occasionally in difficult cases, such as searching for organisations which it was felt should have patented their research but where results were a null return, the date requirement of >= 2010 was removed. Search fields were constrained to Abstract OR Description to limit the number of results generated. In some cases, particularly where filters could be used, Abstract OR Description OR Claims were searched. For example, the "Claims" search term was included when Country analysis was undertaken but not when inventor names were to be harvested. "Inventor/Assignee" names were harvested by downloading the data sets and manually corralling Inventor names and company names because of issues surrounding multiple company entities and the transposing of given/surnames in the patent database.

Example: A typical search for "3D Printing" AND "Additive Manufacturing" AND with the Applicant "TWI" OR "The Welding Institute" OR "WELDING INST" would be written as (ctxt all "3D printing" OR ctxt all "additive manufacturing") AND (pa all "TWI" OR pa all "The Welding Institute" OR pa all "WELDING INST")

To analyse the performance of the UK internationally, queries were made on the patent database with results being presented graphically. The search area was widened to 2005-2022 with data being presented for the ranges 2010-2022. Search terms were (ctxt = "3D printing" OR ctxt = "additive manufacturing") AND pd (publication date) within "year", where "year" is either the stated year of interest (e.g. "2010") or a range of years (e.g. 2005-2022). Text terms searched within: Title, Claims or Abstract. Data were plotted in order of the highest number of patents produced in the range 2005-2022. Plots were constructed as filled area charts with the UK being indicated in red.

All results were filtered for the applicant country and mapped to the top 20 all-time applicant countries.

"To analyse the performance of the UK internationally, queries were made on the patent database with results being presented graphically"

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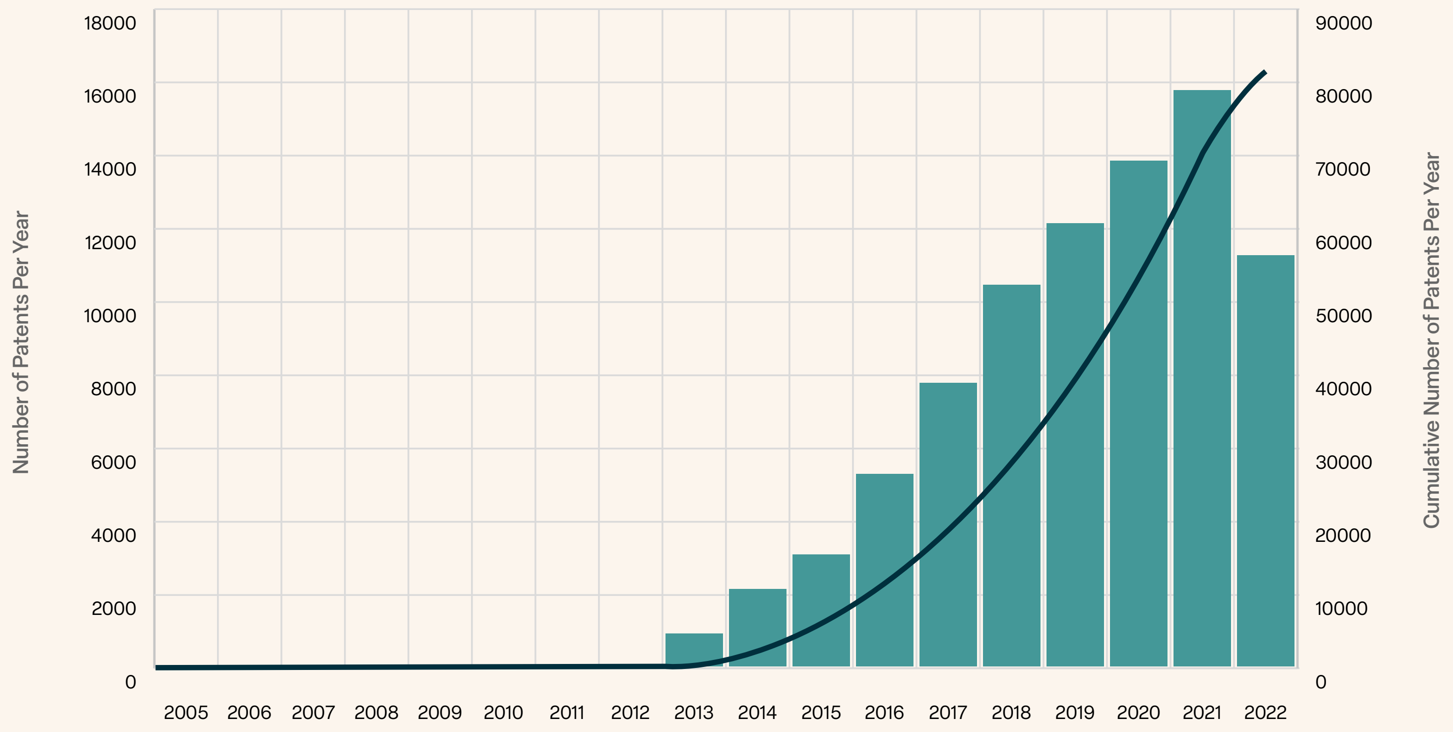

Figure 13 Total AM Patents Published 2005 Onwards

Figure 13 shows the total number of AM patents published internationally since 2005, separated by year and cumulatively from filtered patent database information. AM is a fertile ground for IP protection with over 80,000 patents being published in the period analysed.

Yearly data shows considerable annual increases until 2022, where a considerable reduction to levels below that of 2019 is apparent. This reduction in applications may be a sign of AM development slowing or maturing because of reducing areas of worthwhile investigation.

It should be noted that the patent disclosures are active for 20 years from their respective priority dates, which will be earlier than their publication dates and therefore the protection that these many disclosures have will continue until the 2030s at least.

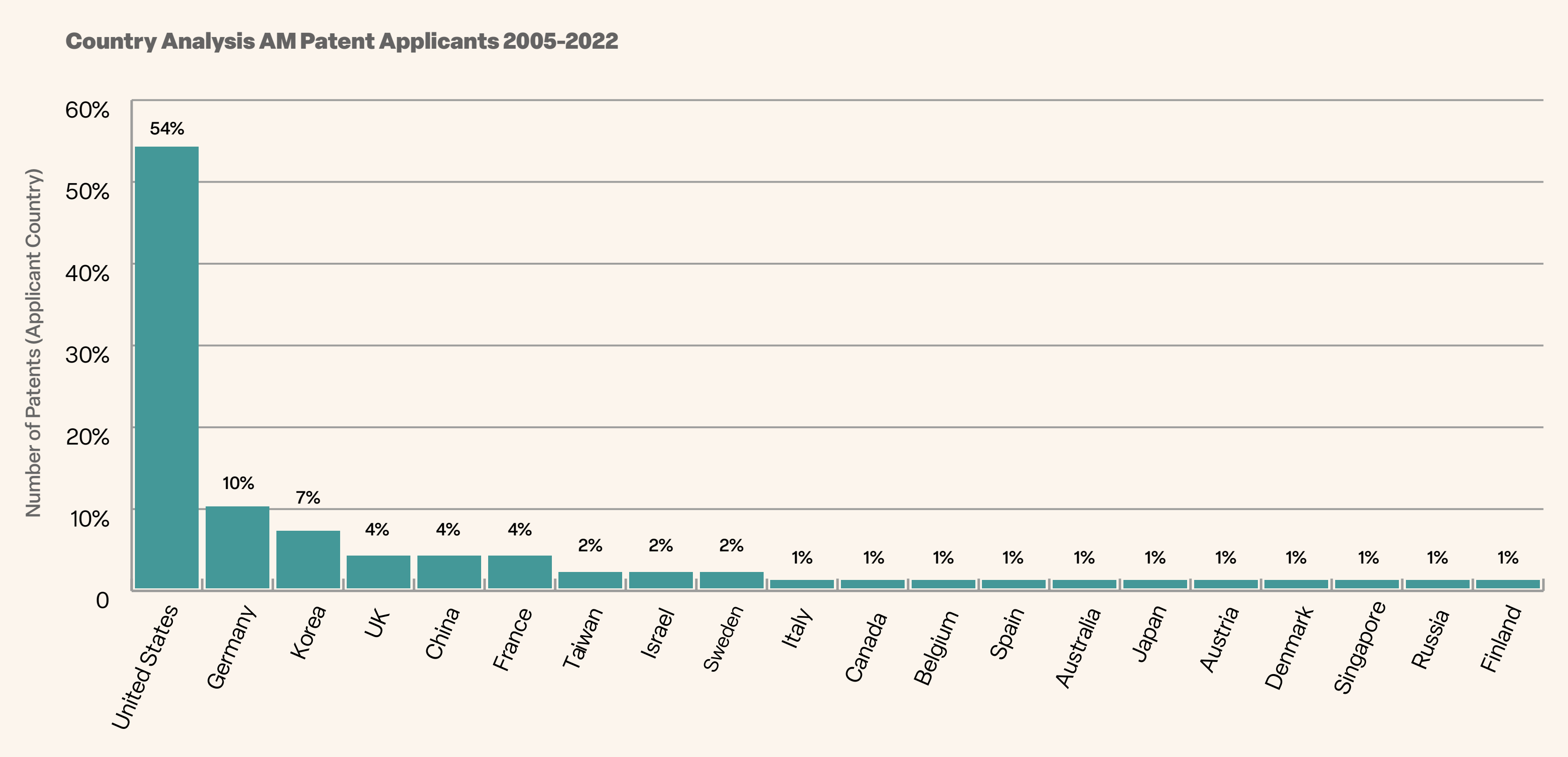

Figure 14 AM Patent Applications Country Analysis

The origin country of the applicants is shown in Figure 14, with the lion's share being taken by the US, with the UK holding 4th place in the world rankings. Disappointingly, the UK only holds some 4% of the global applications, which is less than half that of Germany – a similarly highly developed European economy. China is investing significant effort in the protection of AM-based IP holding a similar 4% of patented AM technology. However, it is interesting to note that China's AM patent portfolio has grown significantly over recent times, contrary to the UK's position where applications have dropped significantly since 2020.

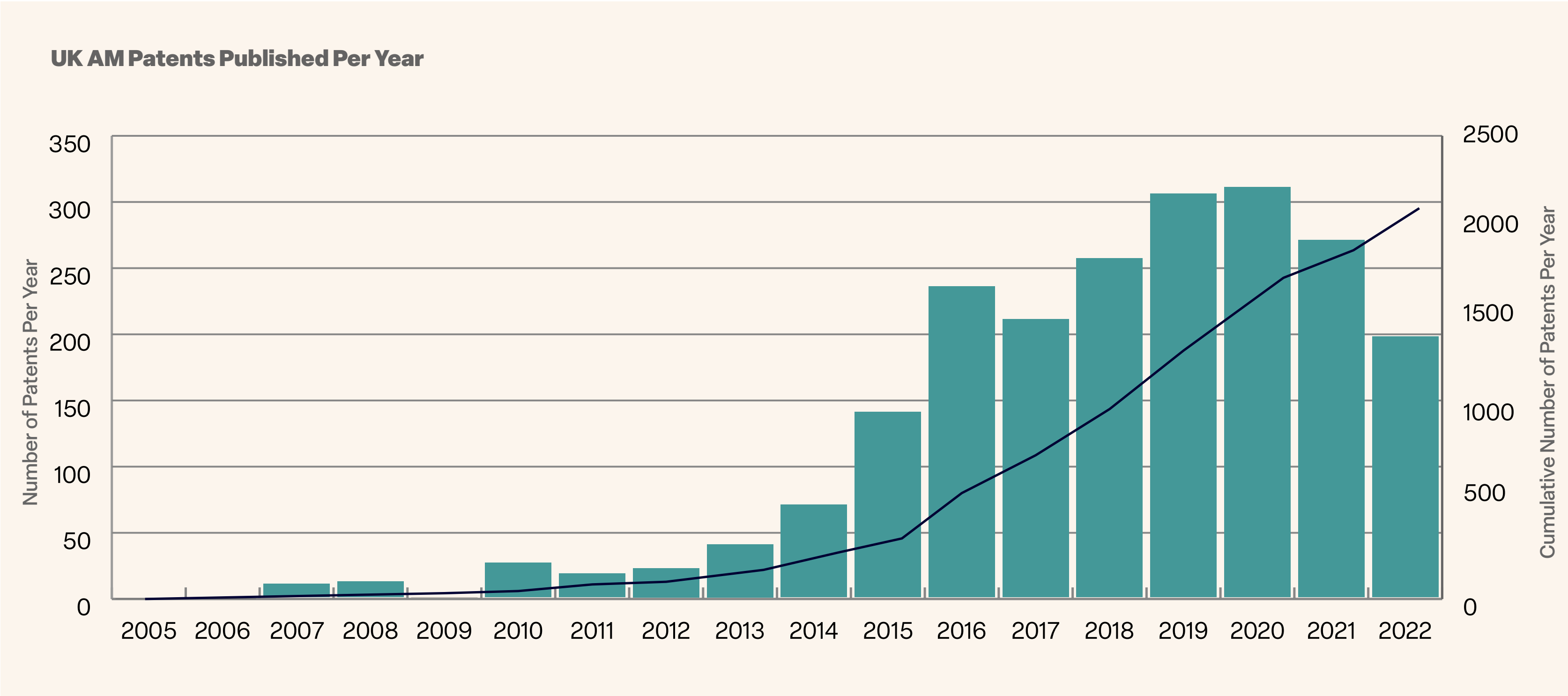

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Figure 15 AM Patent Applications Country Analysis

This yearly UK Patent publication data is shown in Figure 15, where significant reductions in AM patents to pre-2016 levels are apparent. This reduction in patent applications is contrary to government funding records in the AM field (see Figure 3) which shows that the research funding has increased by approximately a factor of three since 2016. It is clear by comparison of these two datasets that whilst the UK is funding AM well, the performance of the sector in protecting IP from this healthy funding stream is under some pressure.

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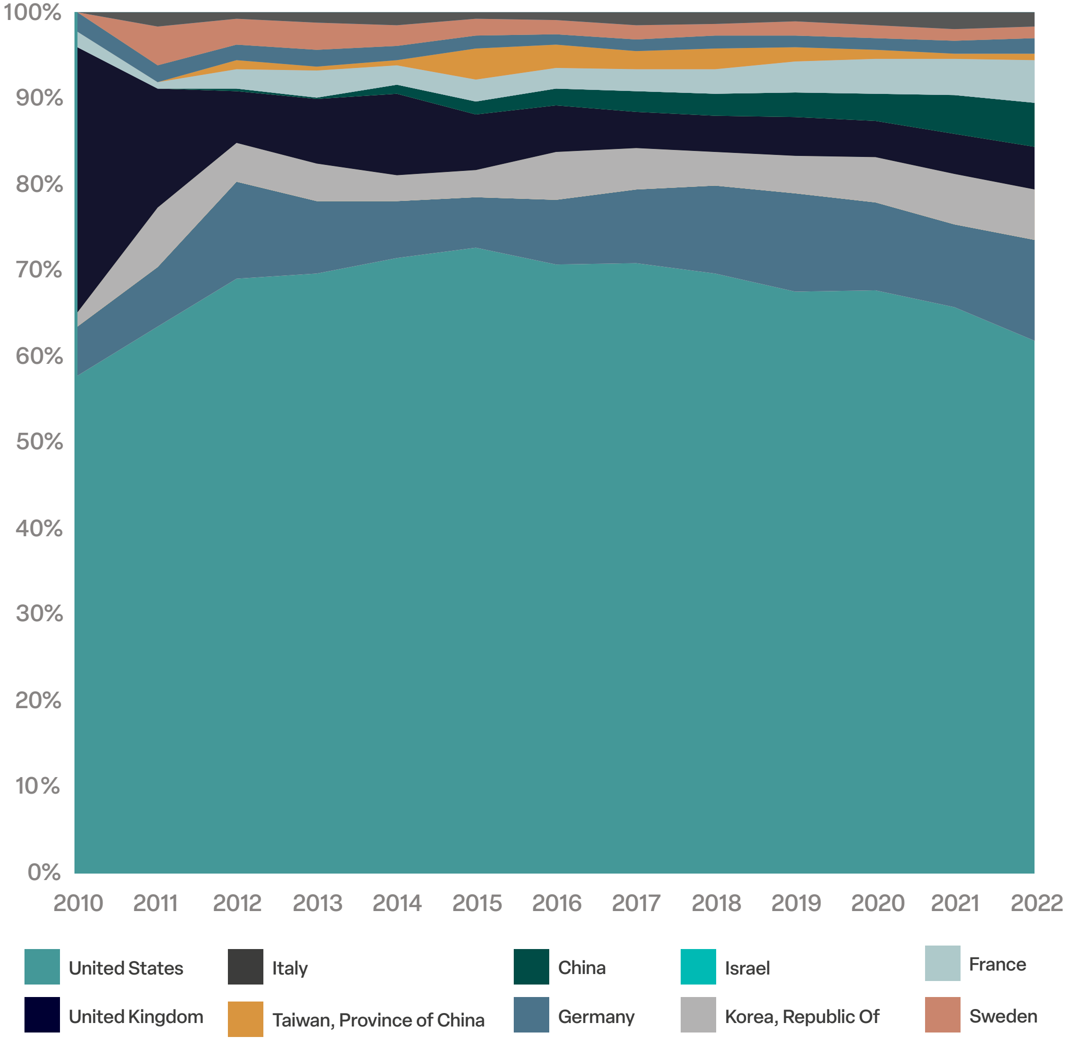

Figure 16 Relative Number of Patent Applications Top 10

◀ **Relative Number of Patent Applicants Based on the Top 10 Patenting Countries**

Figure 16 shows the Relative number of patent applications for the Top 10 countries. In order to make the data more digestible, in this data set, the countries outside the top 10 have been ignored with the Top 10 data representing 100% of the applications. In Figure 16, the UK is shown in red with narrowing share over time illustrating the relative reduction in applications from a particular country.

The UK's data shows that from 2010 the UK's % share performance of patented IP has reduced but steadied from 2017 reflecting the typical reduction in IP activity from the other countries. The US %IP output has reduced significantly since its peak in 2015 but still represents a considerable share of global applicants.

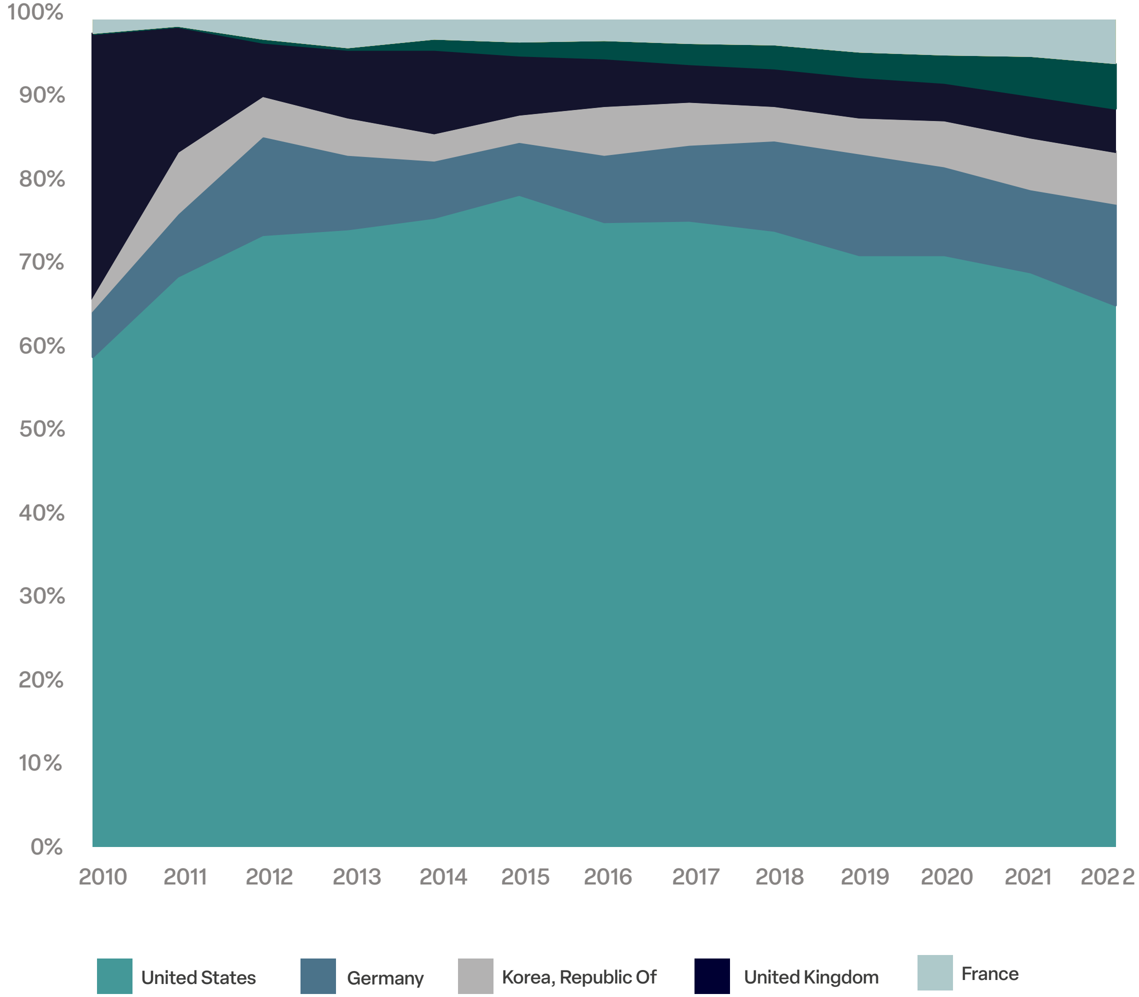

Figure 17 Relative Number of Patent Applications Top 6

◀ **Relative Number of Patent Applicants Top 6 Patenting Countries**

Replotting the data for the UK's nearest performing neighbours reveals Figure 17 which shows the performance of the Top 6 countries. Of note in Figure 17 is the performance of China and France since 2013 with both territories showing increased activity in the area.

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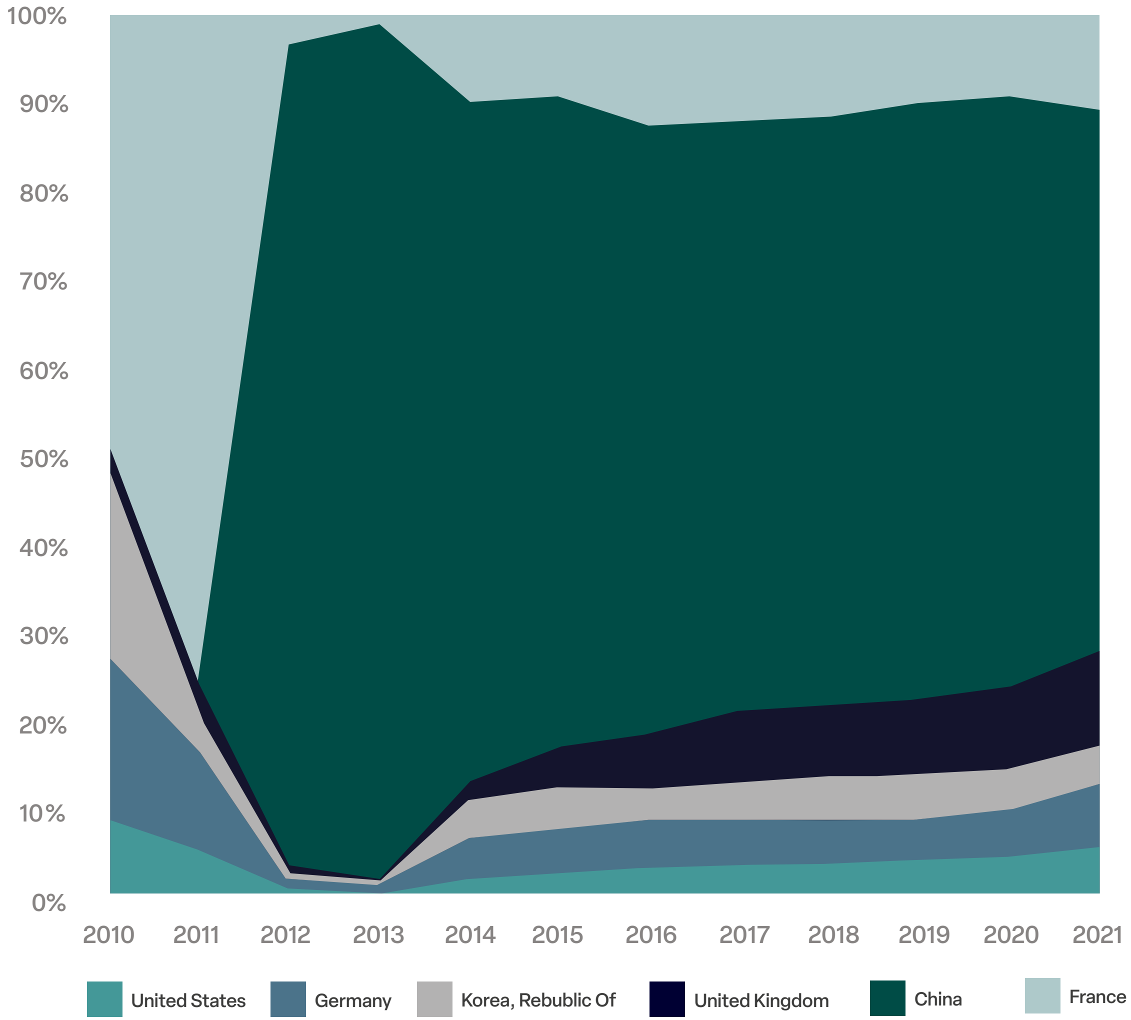

Figure 18 Relative GDP-Based Patent Cost Top 6

Relative Patent Costs Based on GDP Top 6 Patenting Countries

To attempt to normalise the patenting data, and therefore exploitation of research, GDP data for each country was taken from The World Bank and was divided by the number of applicants for each country. This reveals the "GDP cost" per patent, as shown in Figure 18, where wider streams represent relatively higher GDP costs per patent application. Additionally, widening or narrowing shares indicate increasing or decreasing relative costs, respectively, with zero width shares equating to years where no patent applications were published.

In Figure 18 China's significant GDP in comparison to other countries' skews the data and the USA's large number of applicants, probably due to its dominance of well-established AM companies, is illustrated by its considerably narrowed characteristic stream. France, China and the Republic of Korea show data that from 2015 to 2021 is under control with no significant changes in the width of the streams.

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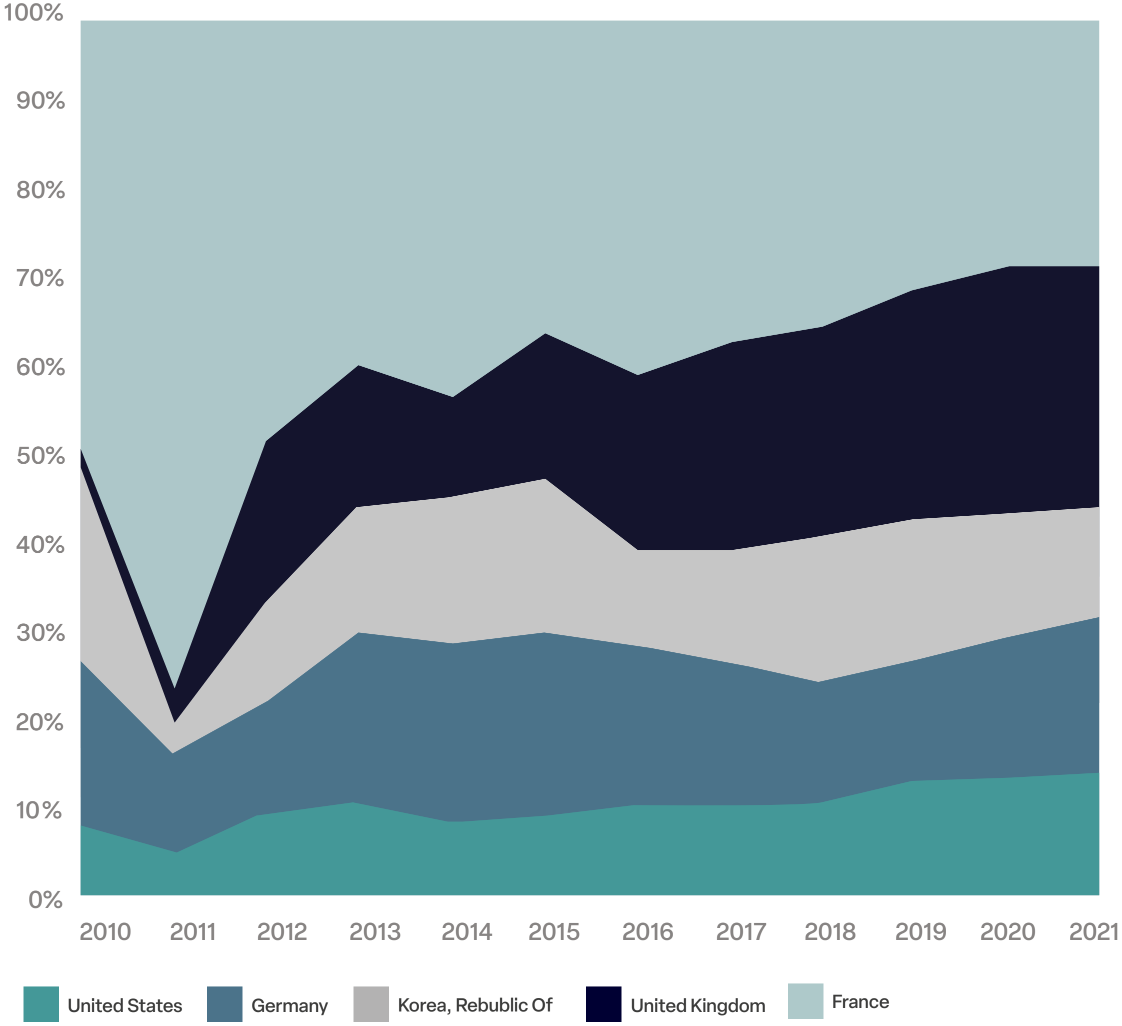

Figure 19 Relative GDP-Based Patent Cost Top 6 (China Removed)

◀ **Relative Patent Costs Based on GDP Top 6 Patenting Countries** (China Removed)

The UK, Germany and the US all show divergent streams indicating that patent application costs based on GDP are increasing. China is the most expensive country in which to protect IP, based on its GDP, but this may be caused by the high GDP of China in comparison to other countries.

Removing China from the analysis, as shown in Figure 19, allows the comparison of patenting costs based on GDP and conclusions to be drawn on relative costs over each country. The lowest cost country in which to capture AM IP based on country GDP in 2021 is The Republic of Korea (61% of the average excluding China) with the US in second place (61% of the average). This is followed by Germany (89%) then the UK (138%) and finally France (140%). The UK and France are therefore approximately 40% more costly than the world average in capturing AM IP based on GDP.

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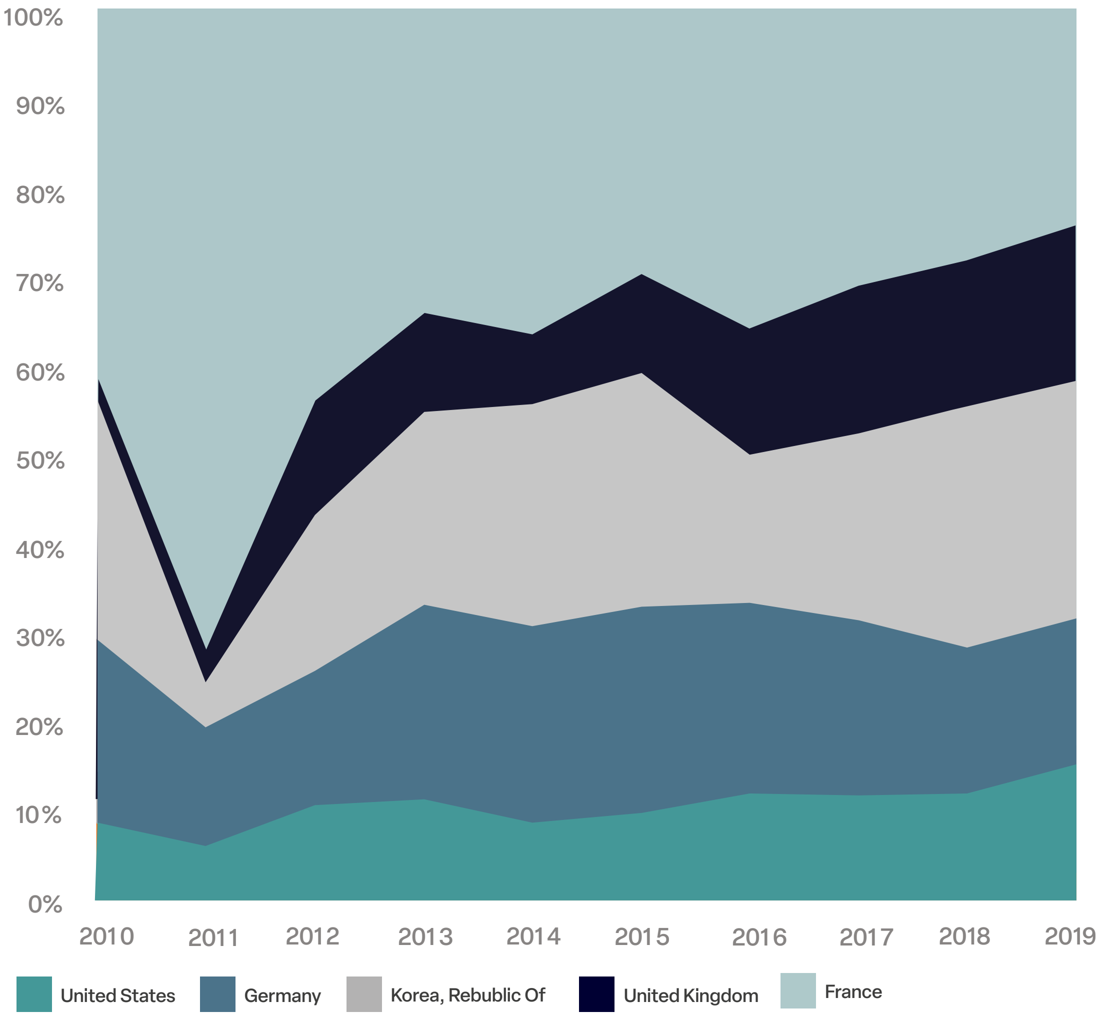

Figure 20 Relative Patent Costs Based on R&D GDP Top 6 Patenting Countries (China Removed)

◀ **Relative Patent Costs Based on R&D GDP Top 6 Patenting Countries** (China Removed)

Different countries, of course, spend different %s of GDP on R&D. Therefore, factoring this effect into the calculations, once again using readily available data from the World Bank and others, is shown in Figure 20, which shows a considerably different picture than if just the GDP-based data is examined. The lowest cost country in which to capture AM IP based on the country's GDP R&D expenditure in 2021 is the US (78% of the average excluding China) with the UK in second place (84% of the average) followed by Germany (86%), France (112%) and finally Republic of Korea (140%). If one calculates the same data for China it spends eight times the average amount of these five countries to capture its IP. It should be noted that the apparently good performance of the UK here could be misleading as, of the countries analysed the UK spends the least GDP on R&D, by some considerable margin.

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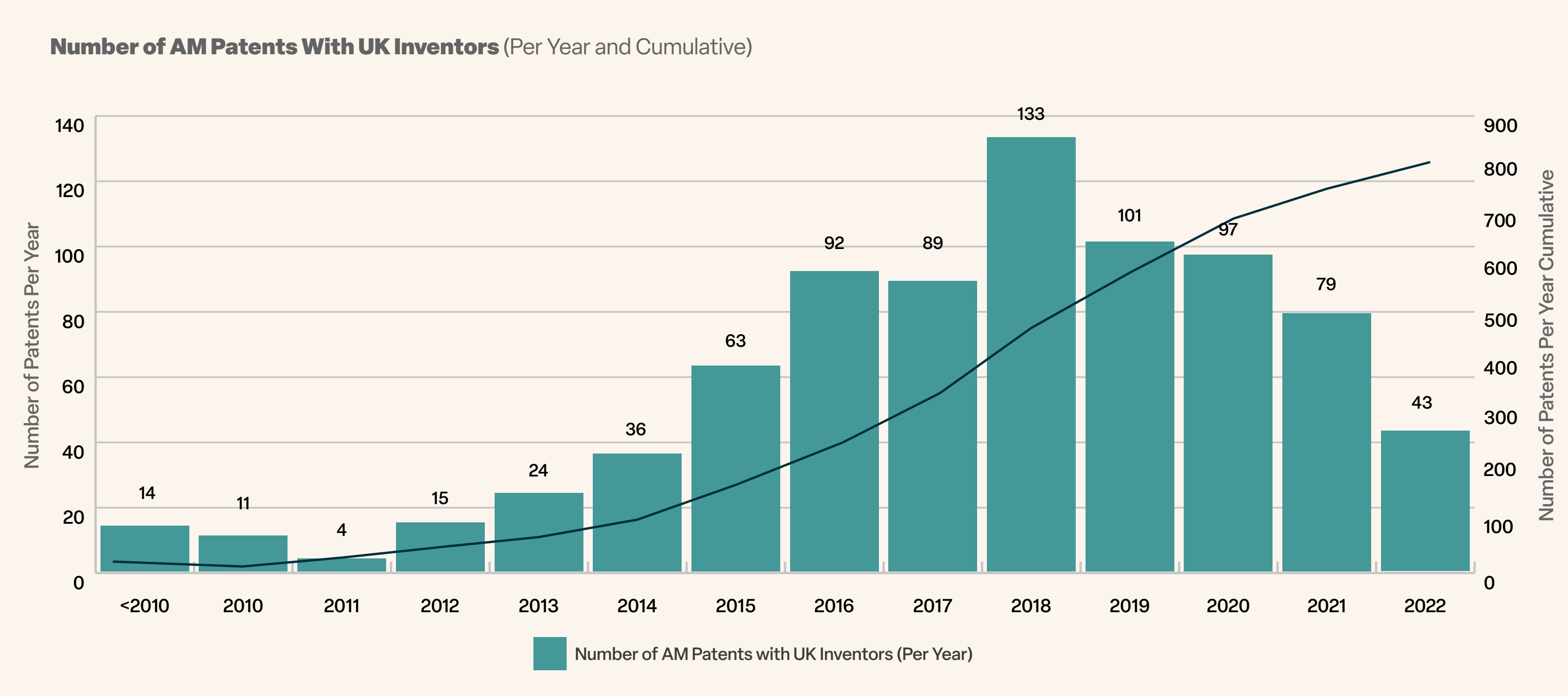

Figure 21 Number of AM Patents with a UK Inventor 2010-2022 (Per Year and Cumulative)

The annual number of UK Inventor patents is shown in Figure 21. Once again, the characteristic downturn in 2019 is to be expected as the impact of the pandemic was felt across the industry. However, there is a significant reduction in IP captured in the UK which raises some concerns.

This reduction could in part be due to the relative reduction in accessible areas for IP capture with the whole of AM being "played out" and, as such, major technical advancements either being captured previously or being significantly more difficult to ideate and exploit.

That said, AM still has considerable challenges to overcome including those of scale, part size, production rate, materials and process control/ repeatability so there are significant opportunities to be exploited.

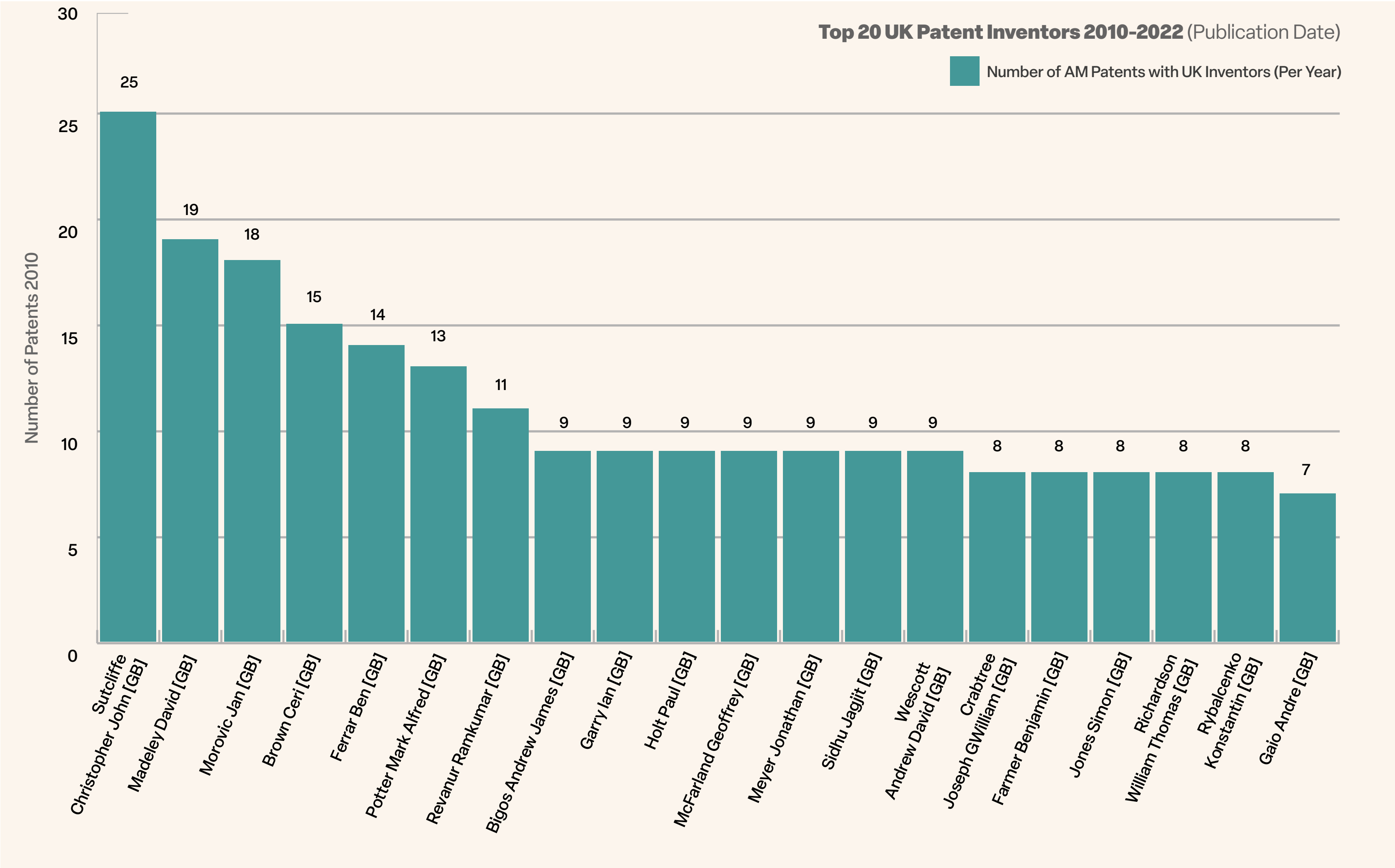

Figure 22 Top 20 UK AM Patent Inventors

02. RESULTS AND DISCUSSION

Producing data for named inventors is difficult to assess because of transposition and the use of shortened names and initials. Data was therefore manually analysed, corralling to ensure that inventors were counted correctly.

The top 25 UK inventors patenting in AM are shown in Figure 22. The list is topped by Sutcliffe (Renishaw and the University of Liverpool) and is dominated by authors from Renishaw (L-PBF AM equipment developers). Renishaw-based inventors include Sutcliffe, Ferrar (Renishaw, LPW and Carpenter Additive), Brown (Renishaw), Revanur (Renishaw and DNAAM) and McFarland (Renishaw) – five in total. Other notable companies are BAE systems with 3 Inventors; Sidhu, Wescott and Potter; Rolls Royce, with two inventors Gary and Jones; EADS and Airbus, with two inventors Meyer and Farmer; and AMT with three inventors, Crabtree, Rybalcenko and Gaio.

Figure 23 shows the Top 25 Patenting UK Universities. Patent titles and abstracts indicate that the most common type of patent is in Methods and Equipment, as shown in Table 8. Here, many modifications or additions to equipment are covered.

Biomedical implantation is another popular field with much of the basic methodology for the production of metallic Implant components being covered by Liverpool, with modifications to this basic methodology being made by Oxford and Imperial College.

Producing data for named inventors is difficult to assess because of transposition and the use of shortened names and initials

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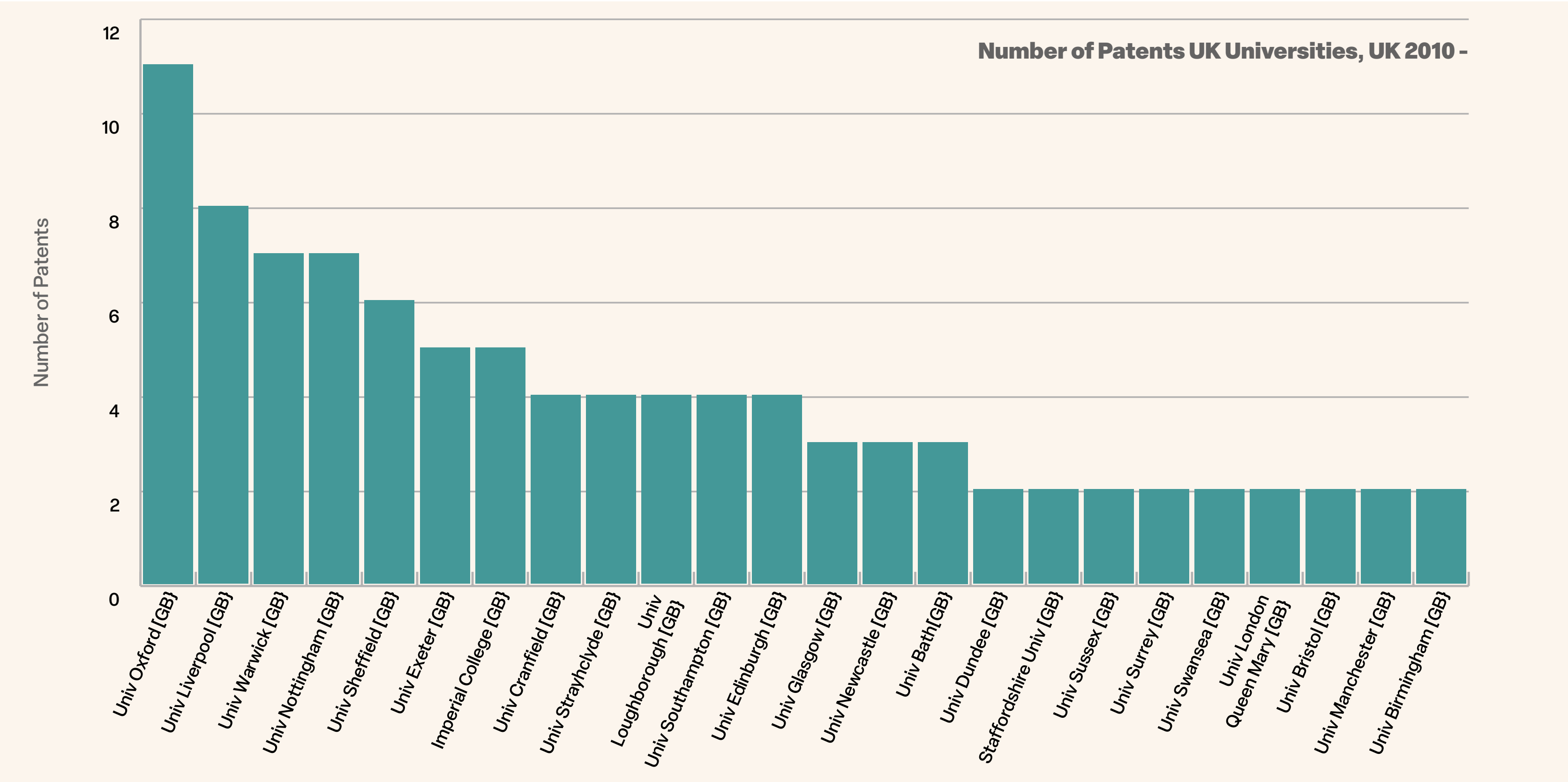

Figure 23 UK Universities Patenting AM Research

Novel methods for the general AM production of "production grade" polymers are covered by Nottingham, similarly, general AM production of metallic materials by Reactive Metallic BJF has been covered by Liverpool. There are many applications in the material space although it is uncertain if any of these advanced modified materials are being taken up commercially as yet. There is a plethora of work on structural materials, particularly complex structures such as lattices being applied in polymers, metals, bio-gels and scaffolds. Other areas of note are the finishing of components, a very important aspect of AM production which has been covered by Warwick.

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Table 8 ▼ Patented Areas for Top 25 Patenting Universities

Applicant University	Patent Areas				
UNIV OXFORD [GB]	Methods/Equipment	Scaffolds	Implants	Structures	Materials
UNIV LIVERPOOL [GB]	Methods/Equipment	Scaffolds	Implants	Structures	Materials
UNIV WARWICK [GB]	Methods/Equipment	Scaffolds	Finishing	Structures	Application
UNIV NOTTINGHAM [GB]	Methods/Equipment	Materials	Implants	Metrology	
UNIV SHEFFIELD [GB]	Methods/Equipment	Materials			
UNIV EXETER [GB]	Methods/Equipment				
IMPERIAL COLLEGE [GB]	Methods/Equipment	Materials	Application	Implants	
UNIV CRANFIELD [GB]	Methods/Equipment	Materials	Application		
UNIV STRATHCLYDE [GB]	Application				
UNIV LOUGHBOROUGH [GB]	Materials				
UNIV SOUTHAMPTON [GB]	Implants	Sensors			
UNIV EDINBURGH [GB]	Materials				
UNIV GLASGOW[GB]	Applications	Sensors			
UNIV NEWCASTLE [GB]	Methods/Equipment	Application			
UNIV BATH [GB]	Design software	Implants			
UNIV DUNDEE [GB]	Applications				
STAFFORDSHIRE UNIV [GB]	Structures				
UNIV SUSSEX [GB]	Sensors	Implants			
UNIV SURREY [GB]	Sensors				
UNIV SWANSEA [GB]	Implants				
UNIV LONDON QUEEN MARY [GB]	Dentistry				
UNIV BRISTOL [GB]	Methods/Equipment	Materials	Implants	Application	
UNIV MANCHESTER [GB]	Methods/Equipment	Materials	Prosthetics		
UNIV BIRMINGHAM [GB]	Structures	Materials			

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02. RESULTS AND DISCUSSION

Taking the top 25 patenting Universities and including the UKRI funding levels for the institutions reveals the data shown in Table 9. It is clear from this data that, similarly to publication numbers, there is a considerable difference in the performance of the institutions. This may be because of high funding rates dwarfing the ability of the university to cope with IP protection requests from academics or Universities allowing their project partners to patent their ideas independently because of costs or a lack of encouragement at the university to protect inventions made in their research.
Similarly, it could be that the better performing institutions are patenting in the AM space without receiving much funding in AM areas. Good examples of this are Surrey and Staffordshire, both of whom have not received any RCUK funding but have patented in AM, perhaps an indication of the richness of IP opportunities.

It is abundantly clear from the data, however, that considering the levels of funding, the opportunities in AM and the drive to produce impact, that UK universities simply aren't proactively patenting the fruits of their work or are instead choosing to publish their results in journals. Comparing the total number of patents from universities (119)

Table 9 ▼ UKRI Research Funding of Top 25 Patenting UK Institutions

Applicant University	UK University No of Patents, 2010 -	Research Funding at this Institute	Research Funding Per Patent
UNIV NEWCASTLE [GB]	3	£ 143,603	£ 47,868
UNIV EDINBURGH [GB]	4	£ 273,264	£ 68,316
UNIV SUSSEX [GB]	2	£ 176,604	£ 88,302
UNIV DUNDEE [GB]	2	£ 240,325	£ 120,163
UNIV OXFORD [GB]	11	£ 1,383,003	£ 125,728
UNIV WARWICK [GB]	7	£ 1,113,450	£ 159,064
UNIV EXETER [GB]	5	£ 1,043,883	£ 208,777
UNIV LIVERPOOL [GB]	8	£ 2,139,983	£ 267,498
UNIV SWANSEA [GB]	2	£ 1,025,110	£ 512,555
UNIV LONDON QUEEN MARY [GB]	2	£ 1,232,782	£ 616,391
UNIV SOUTHAMPTON [GB]	4	£ 3,840,778	£ 960,195
UNIV BATH [GB]	3	£ 3,875,561	£ 1,291,854
UNIV CRANFIELD [GB]	4	£ 6,578,098	£ 1,644,525
UNIV STRATHCLYDE [GB]	4	£ 6,754,507	£ 1,688,627
UNIV GLASGOW[GB]	3	£ 5,783,757	£ 1,927,919
UNIV BIRMINGHAM [GB]	2	£ 5,284,594	£ 2,642,297
UNIV LOUGHBOROUGH [GB]	4	£ 12,192,375	£ 3,048,094
IMPERIAL COLLEGE [GB]	5	£ 18,708,719	£ 3,741,744
UNIV SHEFFIELD [GB]	6	£ 24,383,830	£ 4,063,972
UNIV NOTTINGHAM [GB]	7	£ 29,949,527	£ 4,278,504
UNIV MANCHESTER [GB]	2	£ 9,262,990	£ 4,631,495
UNIV BRISTOL [GB]	2	£ 10,330,025	£ 5,165,013
STAFFORDSHIRE UNIV [GB]	2	-	-
UNIV SURREY [GB]	2	-	-
Averages	4	£ 6,623,489	£ 1,695,404

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to the total number of papers (4500 for the top authors alone) reveals a ratio of almost 40:1 – i.e. Universities are publishing at a rate of 40 academic publications to one patent.

Table 10 details the top 50 patenting UK companies. To collect this data, filters were used in the search terms for the European Patent Database. It should be noted that these filters can yield different results from the patent data described previously, where company details may not be corralled correctly because of their complex corporate naming conventions. Companies may also show as non-UK because multiple applicant names and inventor names appear because “applicant names” occasionally appear within the “applicant” fields.

What is clear is that the list is very much dominated by companies operating in the aerospace industries (Green) and that, secondly, there are UK-based AM equipment suppliers who are patenting their developments (Blue).

Table 10 ▼ Top 50 Patenting UK Companies in AM/3DP

Position	Company	No of Patents
1	Rolls Royce Plc	240
2	BAE Systems Plc	171
3	Renishaw Plc	85
4	Airbus Operations Ltd	71
5	Ansaldo Energia Ip Uk Ltd	32
6	Hewlett Packard Development Co	24
7	Hewlett Packard Development Co LP	24
8	Alstom Technology Ltd	24
9	Johnson Matthey Plc	23
10	LPW Technology Ltd	21
11	Edwards Ltd	20
12	HS Marston Aerospace Ltd	19
13	Additive Manufacturing Tech Ltd	18
14	General Electric Technology Gmbh	17
15	IO Tech Group Ltd	16
16	Airbus Group Ltd	15
17	Cummins Ltd	14
18	De La Rue Int Ltd	13
19	Nicoventures Trading Ltd	13
20	Photocentric Ltd	13
21	Domin Fluid Power Ltd	11
22	Jaguar Land Rover Ltd	11
23	SPI Lasers Uk Ltd	11
24	Airbusgroup Ltd	11
25	Gen Electric Technology GMBH	11
26	Hieta Tech Limited	11
27	EADS UK Ltd	11
28	Embody Orthopaedic Ltd	10
29	GKN Aerospace Services Ltd	10
30	H2GO Power Ltd	10
31	Sony Interactive Entertainment Inc	9
32	Alloyed Ltd	9
33	Blagdon Actuation RES Ltd	9
34	Gen Electric	9
35	Hieta Tech Ltd	8
36	Materials Solutions	8
37	Meyer Jonathan	8
38	Siemens AG	8
39	Sony Interactive Entertainment Europe Ltd	8
40	Victrex MFG Ltd	8
41	Airbus UK Ltd	8
42	Drayson Tech Europe Ltd	8
43	GE Aviat Systems Ltd	7
44	Howmedica Osteonics Corp	7
45	Oliver Crispin Robotics Ltd	7
46	Reliance Prec Limited	7
47	Rolls Royce Corp	7
48	British Telecomm	7
49	Clear Amber Group Ltd	7
50	IP2IPO Innovations Ltd	7

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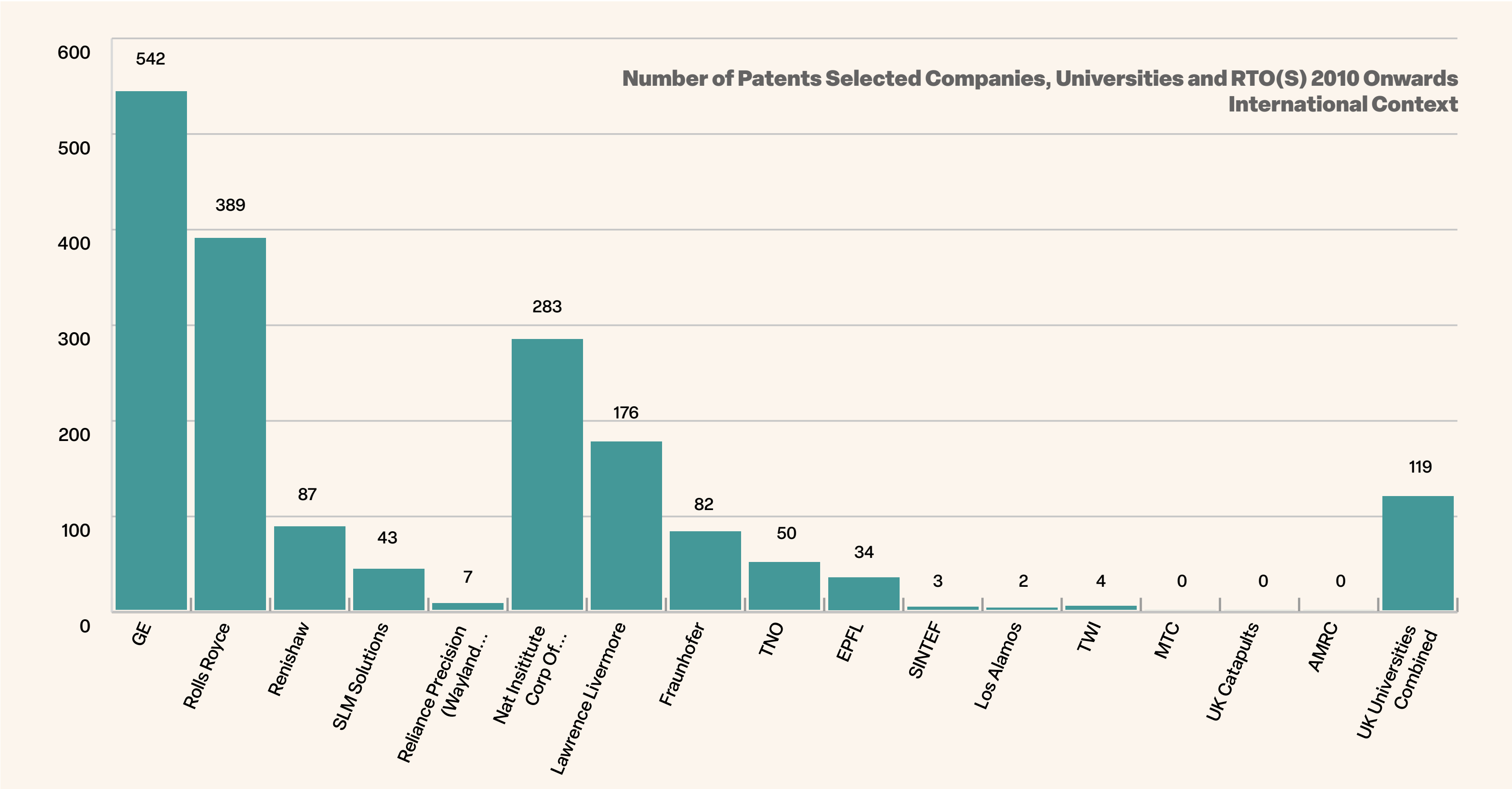

Figure 24 Selected Entities Patenting (Companies, Universities and RTOs) International Context

Further analysing the data and comparing it to the international patenting scene reveals the data shown graphically in Figure 24. Categorising the data shows the relative performance in different sectors of the industry.

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02. RESULTS AND DISCUSSION

In the Aerospace industry, GE is patenting at a higher rate than Rolls Royce. However, it is important to note that GE also owns Concept Laser and Arcam, both AM equipment Manufacturers, which may skew the data in favour of GE. Renishaw is patenting its inventions at a higher rate than its competitor SLM Solutions which is encouraging. However, the new company, Wayland Additive, appear to have a significant way to go in protecting its technological development if they are to become serious international players in the AM market.

In terms of Patents from the RTOs, it is clear that overseas entities are patenting at a significantly higher rate compared to UK based RTOs. The National Institute Corporation for Additive Manufacturing (China) has published almost 300 patents in comparison to 176 from Lawrence Livermore National Labs (US), thereby indicating the level of current interest in developing AM from RTOs in China. The Fraunhofer Centres lead the way in Europe with 82 patents followed by long-established AM advocates, TNO (NL), with 50 applications. What is striking from the data is the apparently poor performance of the UK's Fraunhofer-like RTOs (particularly the Catapults), with practically no patents being produced by this network. This could be for several reasons: potentially the centres such as TWI, MTC, AMRC and the wider UK Catapults, do not assign patents to themselves but rather directly license their inventions to their industrial partners; perhaps they do not feel that it is their responsibility to protect their inventions or do not have sufficient resources, staff or time to protect their IP. However, it is clear that there is little or no detected activity from UK RTOs which can only be described as disappointing in comparison to their international peers. It should be noted that potentially their results simply aren't being found in the searches undertaken; to counter this, all searches and multiple names were used and the search area widened significantly to try to capture their contribution to no avail.

UK universities seem to fair better in terms of raw numbers, performing better than the whole Fraunhofer network in terms of raw numbers. Whether this good relative performance from UK universities can be successfully translated into an exploitable product is, however, uncertain. No analysis of European or American Universities was undertaken because of the significant amount of data that would have to be analysed, and is thus beyond the scope of this study.

> In terms of Patents from the RTOs, it is clear that overseas entities are patenting at a significantly higher rate compared to UK based RTOs

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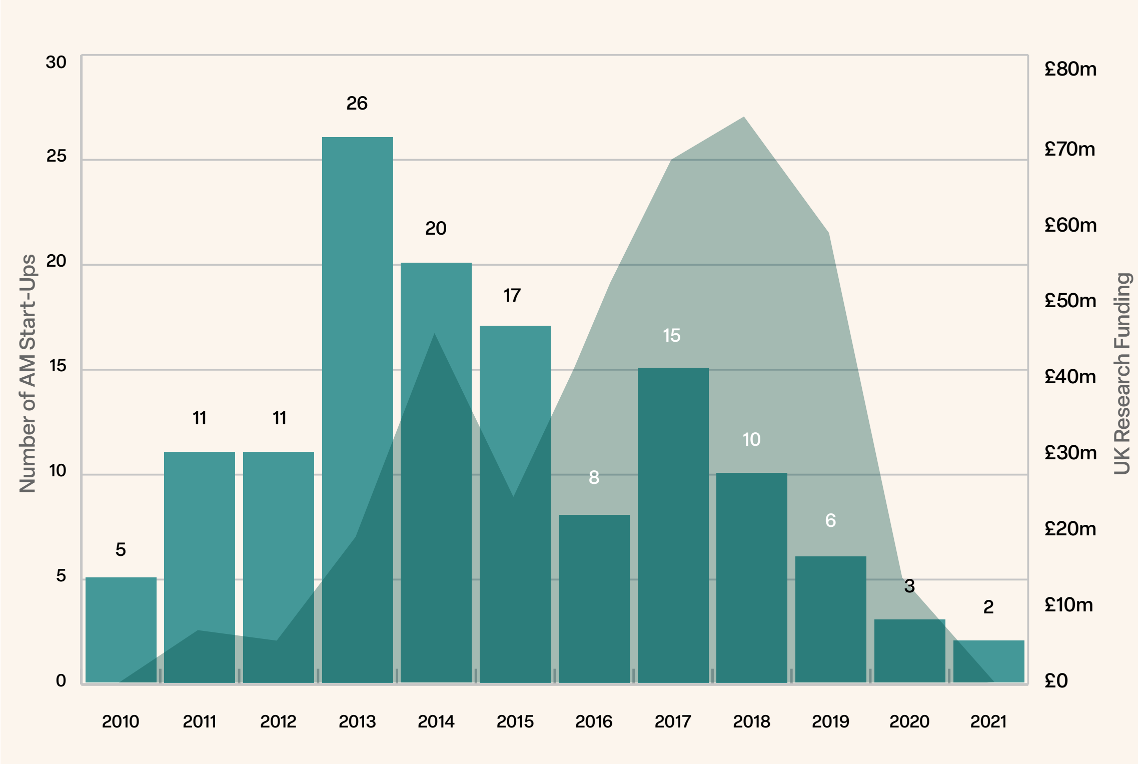

◀ **Number of UK AM Start-Ups By Year in Comparison to UK Research Funding**

Figure 25 UK AM Start-up Numbers and Corresponding UKRI Funding Levels

UK AM Start-up Landscape

Crunchbase was used to garner data on UK start-up companies operating in AM, as shown in Figure 25. In total 134 AM start-up companies were found in the period 2010-2021 – an average of just over 11 per year, which is potentially considered low based the total amount of funding from UKRI. This data was further manually triaged to 90 companies by removing dissolved or non-relevant companies. There has been a clear drop in start-up numbers from 2013 onwards. The number of start-ups does not seem to bear any relationship to the funding from UKRI, and it seems that the considerable increase in funding provided by Innovate UK and the research councils has not affected the number of start-ups being set up in the UK.

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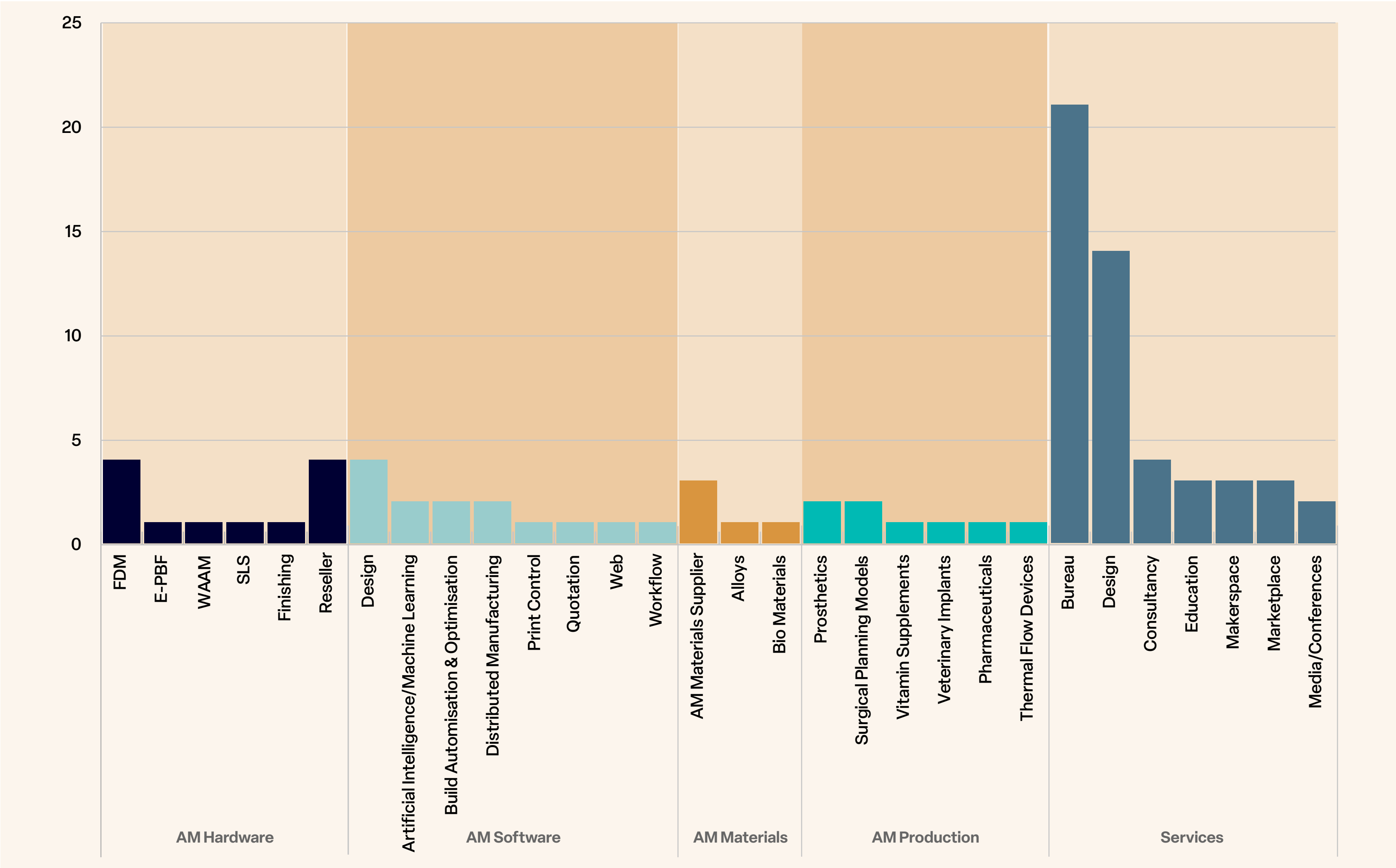

Figure 26 UK AM Start-ups Sorted by Operating Area

Figure 26 shows the areas of operation of the start-up companies, as gathered from CrunchBase. Operating areas were defined from analysis of the description of the companies in the downloaded data and browsing websites. Whilst the operating area of the start-up is considered accurate these fast-developing companies may have changed considerably between their incorporation and today.

> AM production also includes diverse applications of using AM to produce end-user parts, as opposed to parts aimed at prototyping or short-run parts

Five broad categories were found in the data and no effort has been made to align these categories with previous reports. The five categories were, AM Hardware, AM Software, AM Materials, AM Production and Services. It is clear from the data presented in Figure 26 that AM Services is the most populated category. This is understandable as there is a lower barrier to entry in this category than the others.

For example, it is relatively simple to set up a service bureau or a design consultancy as there is little need to do anything other than purchase standard capital equipment and put together a sales and marketing strategy. Similarly, consultancy and education companies in this category are reliant in the main on the experience and skill of their founders and there is little need for any further investment beyond this. One notable example is Added Scientific (University of Nottingham spin-out) which not only utilises the skills and knowledge of its founders but undertakes materials, IP and hardware development. What is clear is that there are considerably more companies set up in this category than in the other higher barrier-to-entry categories analysed.

AM production also includes diverse applications of using AM to produce end-user parts, as opposed to parts aimed at prototyping or short-run parts. A total of only eight companies were found which are aimed at producing items by AM that have production intent. The most populated subcategories are prosthetics and surgical planning models. Here, AM has many unique advantages that make it ideally suited for production. In particular, the ability of AM to link directly to the digital data produced by medics is the key advantage alongside the fact that the parts produced have limited requirements for loading or thermal performance and that materials have been developed over decades for this application. More complex applications include the development of edible vitamin supplements (Nourished Ltd) which are custom tailored to the person taking them; orthopaedic implants and fracture management implants for veterinary applications (Fusion Implants Ltd); and thermal engineering technology enabled by the ability of AM to make complex devices (Hieta Ltd),
There are five start-up AM Materials companies in the period analysed with the most populated sub-category being materials supply, which is mainly filament supply companies for FDM technology.

02. RESULTS AND DISCUSSION

Only one company (Alloyed) was set up in the period to develop speciality alloy powders for AM – though it should be noted that LPW (now Carpenter Additive), a global player in AM powder development and supply, was set up in 2007, outside the date range analysed. It is also probable that many AM alloy powder suppliers are simply making alloy powders as part of their existing materials development and supply activities. A good example of this would be Liberty Powder Metals or Sandvik Osprey who both developed AM-specific products in the period, diversifying their operations, with AM playing a smaller role in their overall business. There was just one business start-up in the Bio-Medical field, which is surprising considering the number of projects funded in this area. 4D Biomaterials develops, manufactures and supplies resorbable polymers for application in implantable scaffolds and tissue engineering.

The development of AM software is a fertile field for the UK with 14 start-ups operating in this category. Analysing the products of each company, the incorporation of companies developing design software was the most populated subcategory with all companies providing DfAM based on complex structure designs such as lattices and TPMS development tools. AI/ML techniques were commercialised by two companies (Intellegens and Ai Build). Intellegens Ltd produces tools that help scientists and engineers to get the most from their data using Ai/ML to home in on correct process parameters, whilst Ai Build Ltd produces software for automated AM toolpath generation. Companies set up for the development of distributed manufacturing include Grow and 3DC Ltd. The remainder of the software companies develop tools that help automate or control the AM process, including print control, quotation and AM workflows.

The AM hardware category is dominated by resellers and those developing FDM-based consumer hardware and as such, they are of little interest to this report as resellers are essentially sales channels for the large overseas-based equipment developers and FDM consumer hardware does not require significant and ongoing governmental support. Other UK-based start-ups tend to operate at the cutting edge of AM hardware and include several very innovative companies. For example, Wayland Additive has developed an Electron Beam Powder Bed Fusion System that considerably extends the state of the art of this method by alleviating the challenging problem of charge accumulation in the powder bed. WAAM3D ideated and developed the wire arc method for metallic AM parts and is capable of manufacturing very large and highly engineered parts for several industries, including but not limited to Aerospace, tooling and military applications. Xaar3D (now acquired by Stratasys) develops its patented Selective Absorption Fusion (SAF) process for the rapid production of polymeric components and AMT is a globally respected developer of equipment for the finishing of AM components.

03. CONCLUSIONS

1. A review has been undertaken of the AM landscape in the UK

- **a.** AM in the UK is a healthy and active field
- **b.** Recommendations from the AMUK report have been reviewed and found to be lacking in areas and this must, and is being addressed in part

2. AM funding

- **a.** The UK research activity is well funded
- **b.** AM funding has been significantly affected by the impacts of the pandemic
- **c.** University based R&D is dominated by institutions garnering multiple research awards. This is to be expected, however the performance of these well-funded institutions in terms of knowledge exploitation must be further examined to ensure that the fruits of invention are not given away by high and perhaps unnecessary publication
- **d.** The split between universities companies and RTO's seems balanced, however the content of research activities needs more focus, particularly from the RTO's and Catapult network on knowledge generation for profit

3. Research Publications

- **a.** The UK produces many research publications probably driven by the reward ecosystem which merits publication rate at university above IP capture
- **b.** The UK is well placed on the international scene in terms of AM publications
- **c.** Several institutions are performing very well by publishing at high rates with little funding
- **d.** Several universities have garnered large amounts of funding for AM research but have produced relatively little in terms of academic paper output
- **e.** The rate of publication considerably exceeds the rate of IP capture

4. AM Patent Landscape

- **a.** The UK is still producing AM based IP currently ranking 4th globally
- **b.** The IP capture rate for the UK has reduced significantly in the period analysed
- **c.** The cost of IP capture per research £ spent has increased and is continuing to increase in the UK
- **d.** Several competitor countries have significantly increased their % of AM based IP including China
- **e.** UK spend on GDP based R&D overall is low compared to competitor economies
- **f.** RTD and Catapults seem to have little or no patent-based activity, at least no evidence was found in this work of this activity
- **g.** UK universities do have an IP based activity but it remains to be seen if these activities are better or worse than competitor countries as this was not analysed. What can be said is that UK universities perform slightly better then the Fraunhofer network in Germany, however, it should be noted that the funding is across all UK universities and the number of institution and their funding is significantly higher than that at the Fraunhofer network.

5. AM Start-up Landscape

- **a.** The UK produces some start-ups
- **b.** Triaged data shows less than 100 AM start-ups were established during the review period. This is a poor performance considering the funding rates
- **c.** The number of start-ups has steadily reduced since 2013 which is the opposite trend to funding in AM which calls into question if the funding mechanism has worked

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03. CONCLUSIONS

d. AM based start-ups are mainly based in the AM services sector which isn't a sector that is served substantially by R&D funding

e. Removing the AM services sector from the data shoes a poor position for the AM industry in producing start-ups, is there an AM start-up culture in the UK?

Clearly there is a lot of fundamental research in AM in the UK but has that fundamental AM research been properly exploited. The conclusions from this research seem to indicate otherwise. If our institution can publish huge volumes of papers then why is this not reflected in an enthusiastic and vibrant start up nation.

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