Additive Manufacturing Education in the UK

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Introduction

There has been and continues to be a considerable effort regarding education for Additive Manufacturing (AM) in the UK. This generally started in 1992 with a seminar organised by the Institution of Mechanical Engineers and an industrial exhibition stand at Mach 92. However, before the education activities are discussed it is useful to show the AM research landscape in the UK as this will give an indication of the level of activity It should be noted that there will also be a considerable number of organisations involved in using AM but not involved in research.

The UK landscape for AM Research

This paper contains statistical data derived from a study undertaken by Econolyst Ltd for the Additive Manufacturing (AM) Special Interest Group (AM-SIG), coordinated by the Materials Knowledge Transfer Network (KTN) at the request of the UK's Technology Strategy Board (TSB). As such it should be considered as a 'snapshot' of the UK AM research community in Q1 of 2012 and looks at the period from 2006 to 2012.

Overview of UK AM research community

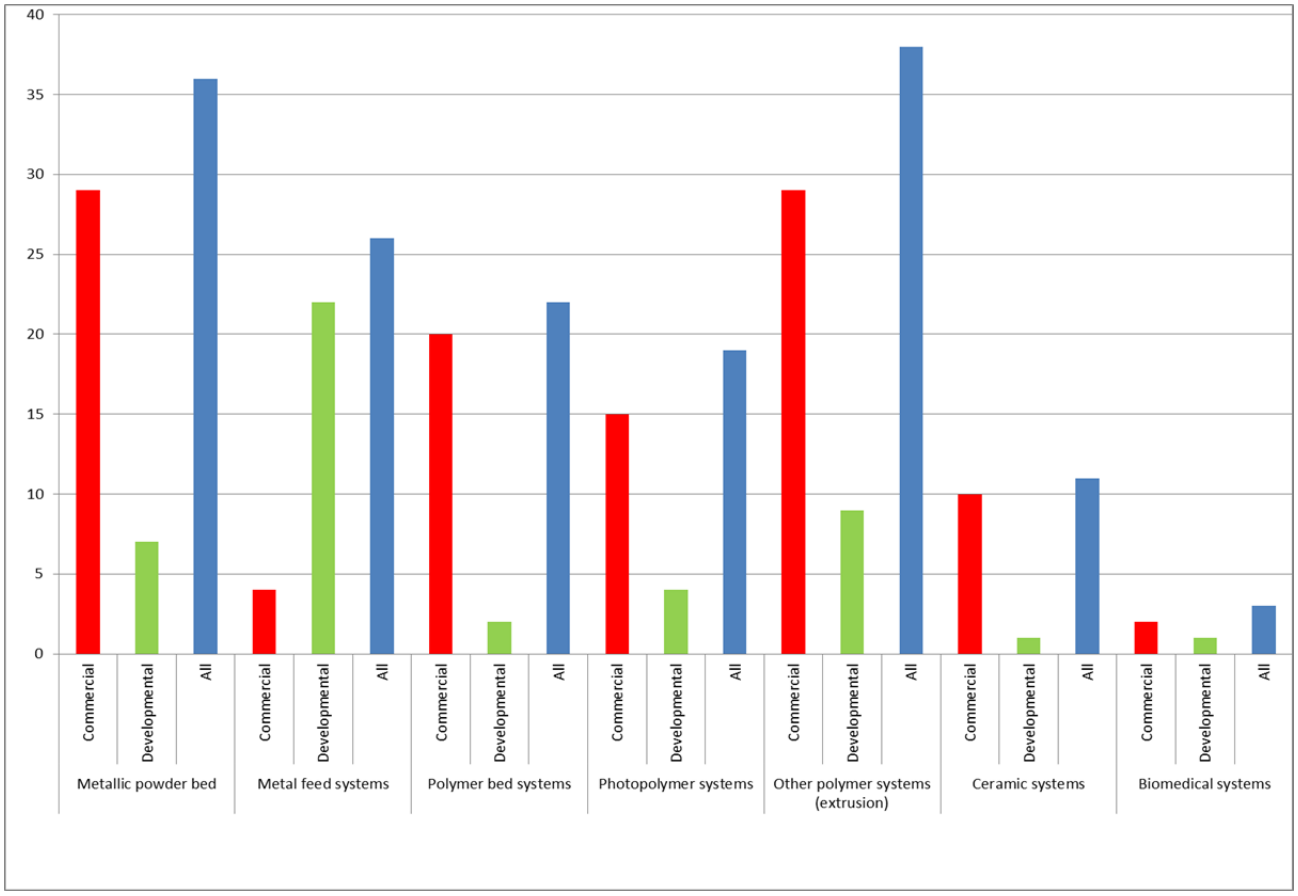
81 organizations within the UK have been identified as currently or previously (back to 2007) engaging in AM research activities. This includes 24 Universities and 57 companies, as detailed in Figure 1.

Figure 1 - List of organizations included in AM SIG research review process

Universities & Research Technology Organizations (RTO's)		
Bath University	Exeter	Materials Solutions
Birmingham City (JIIC)	Glasgow Caledonian	Newcastle
Birmingham University	Lancaster	Nottingham
Cambridge University	Lboro	Sheffield University
Cardiff University	Leicester	TWI
CERAM	Liverpool	University of East Anglia
Cranfield	London metropolitan	Warwick
DMU	Manchester	Wolverhampton

Within these 81 organizations, 151 AM machine platforms have been identified, including 109 commercial machine tools procured from technology vendors, and 46 machines either modified from commercial machines (for specific research tasks), or self-assembled using modular elements such as robots, gantries, lasers and material feed nozzles. A detailed breakdown of machines by technology class within the UK can be seen in Figure 2.

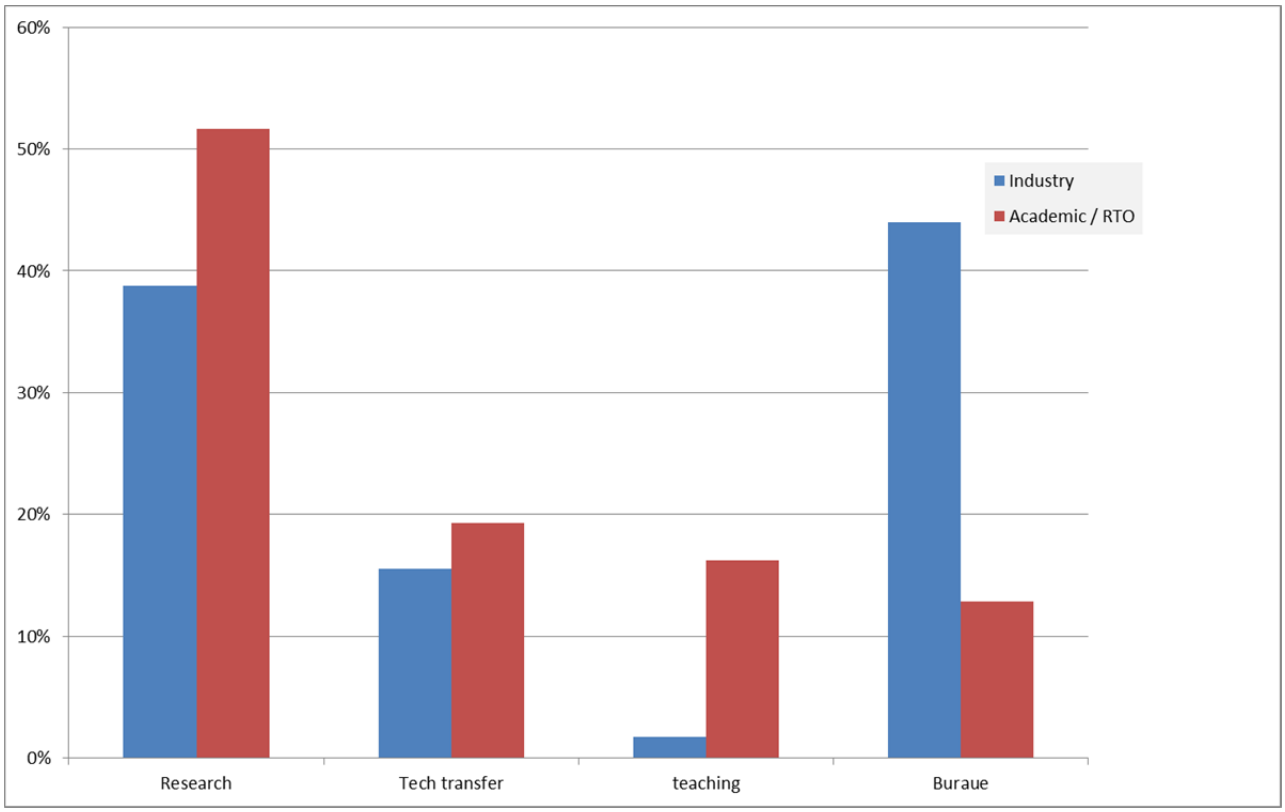
Figure 2 - Distribution of AM machine platforms in the UK used for research



Of the installed machine base within the UK, 52% of University machine capacity is used directly for research. This compares to just 38% within industry, where machines are used to support prototyping and low volume production applications.

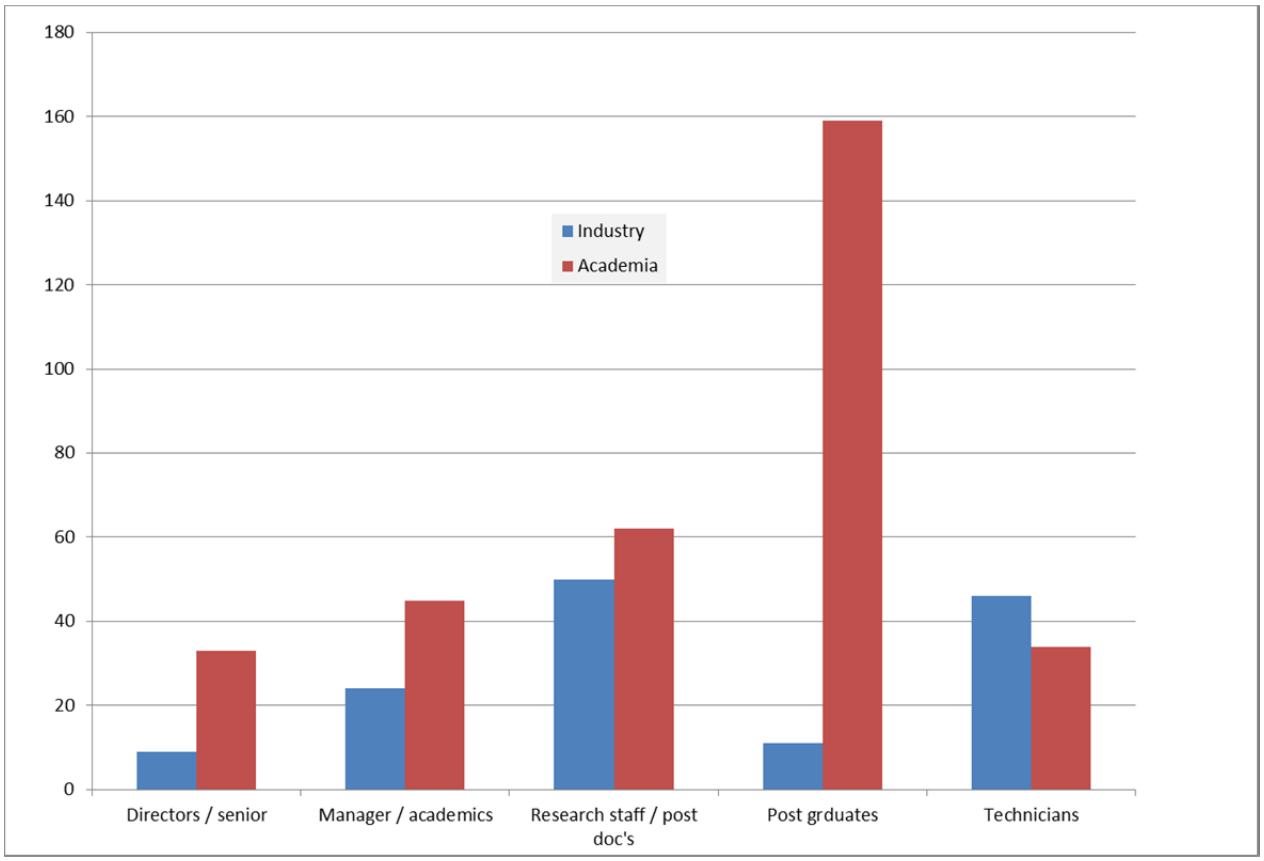
A detailed analysis of machine usage within the organizations canvased in this research can be found in Figure 3.

Figure 3 - AM technology usage profile for industrial and research organizations



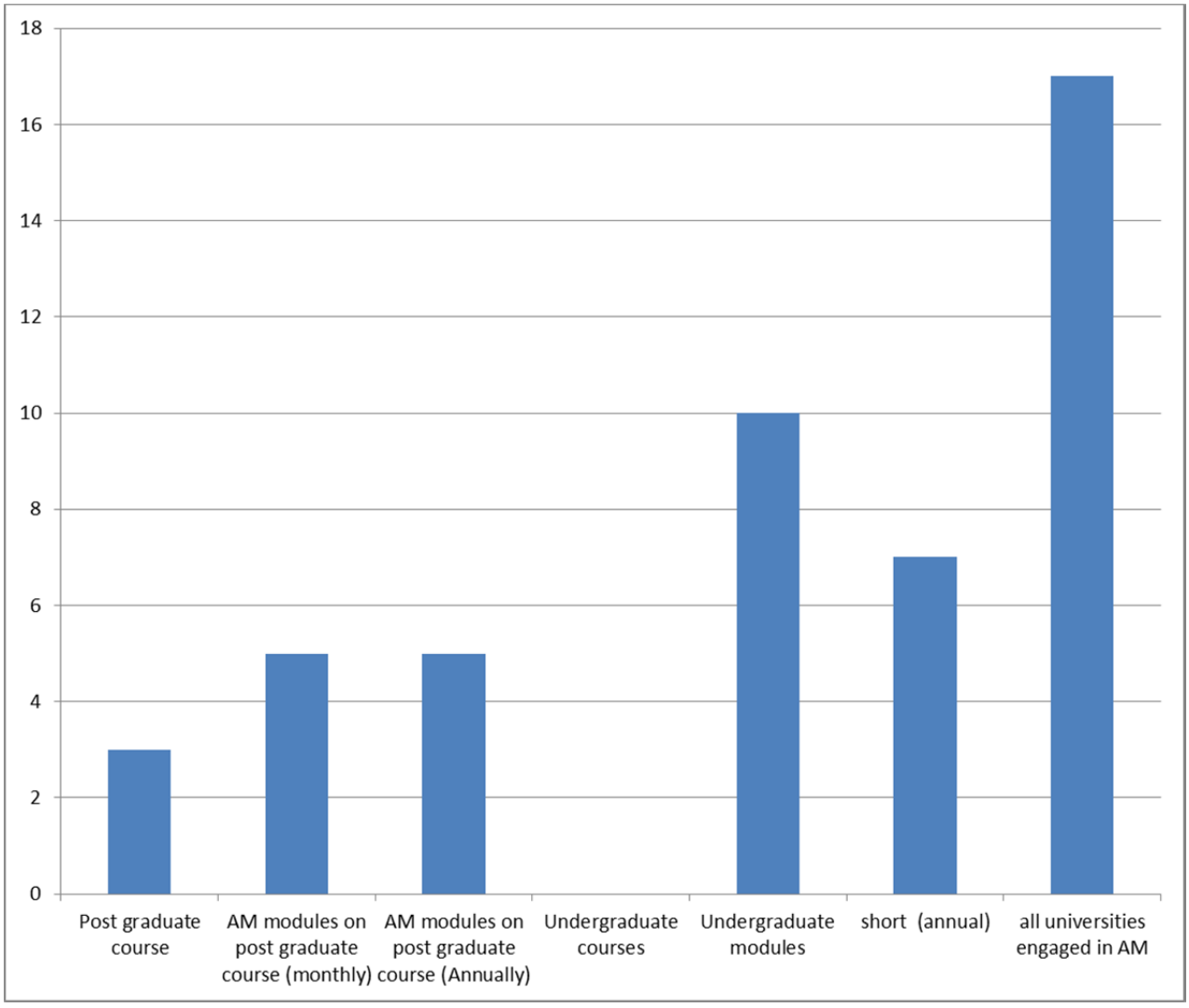
The largest percentage of employment in both academic and industrial establishments is at a post graduate or post-doctoral level, as opposed to a technician level, as detailed in Figure 4.

Figure 4 - Typical distribution of staff within UK AM research facilities



AM education is cascading down to an undergraduate level, with 17 universities across the UK engaged in the delivery of AM related teaching or training courses, ranging from dedicated post-graduate courses at De Montfort and Wolverhampton Universities, though to under graduate modules delivered at 10 Universities up and down the country. It should be noted however that as yet, there are no dedicated Additive Manufacturing or 3D Printing undergraduate offerings. A detailed breakdown of AM teaching and training provision within the UK can be found in Figure 5.

Figure 5 - AM teaching & training activity within the UK



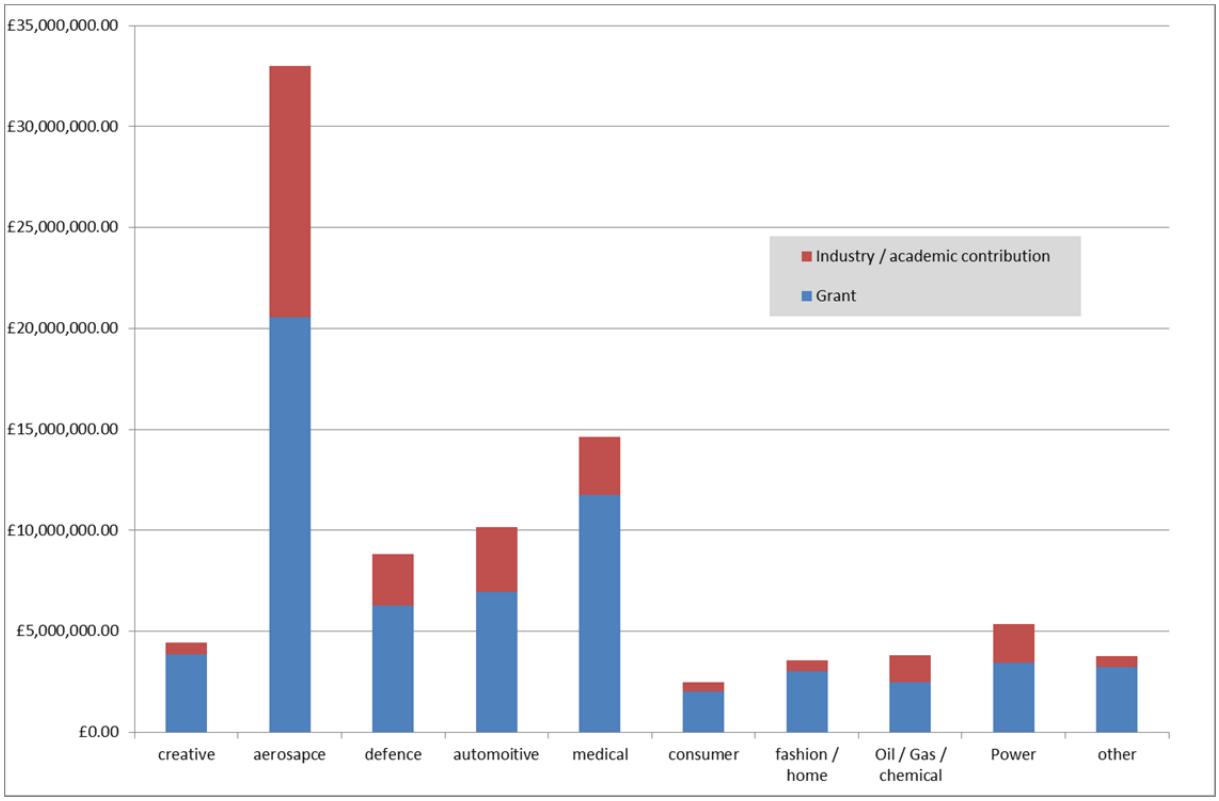
Investment into AM Research and Technology Transfer within the UK

Between 2007 and 2016, £95.6-million has either been invested, or is committed to be invested in UK Additive Manufacturing research & technology transfer activities within the organizations listed in Figure 1. This includes £80-million of research focused monies and £15.6-million of funding for technology transfer activities. Of this funding, the largest proportion, £24.9-million has come directly from industry, with approximately £13-million contributed each by the TSB, EU Framework Programs (FP6 & FP7), and the European Regional Development Fund (ERDF).

Investment in industrial AM R&D activities

By sector, aerospace has received the largest grant investment to support AM research (£20.5-million to industry & universities combined), albeit the sector has also made the largest private sector direct investment (£13-million), as detailed in Figure 6. The medical sector has been the second largest beneficiary of research funding (£12-million), but has contributed only £3-million directly to AM research activities through matched funding. This is slightly less than the automotive sector who have invested some £3.5-million, but which has only received grant support of £7-million. In short, aerospace has invested in and benefited from AM research beyond any other sector.

Figure 6 - AM R&D investment by sector & sources (2007 - 2016)

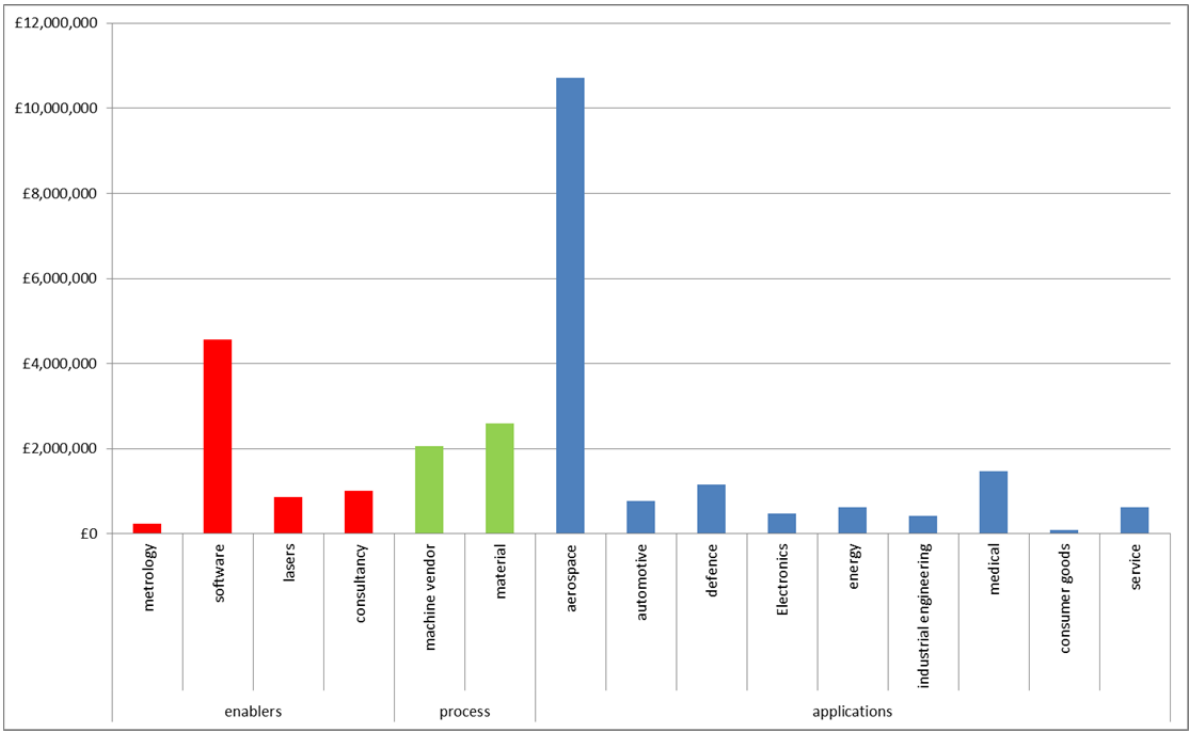


Further analysis shows the split of R&D investment between industry and academia, based on grant and match funding together. Aerospace businesses have received a similar level of direct grant funding to the investment they have made. The creative industries and the fashion sectors on the other hand have received very little funding directly, with the majority of grant funding going directly to research organizations such as Universities. Although only accounting for a small proportion of research activity, the oil, gas & chemicals sectors and the power generation sector have all received direct funding relative to their industry investment, at a rate on par with the aerospace sector.

In summary, they have benefited from similar levels of funding, but have engaged in a much lower level of research activity.

In terms of direct investment by the private sectors across the whole AM supply chain, aerospace dominated the applications / user domain, driven by companies including Boeing, Bombardier, EADS, Messier Dowty, Rolls Royce and Aero Engine Controls. After the aerospace sector, as detailed in Figure 7, the greatest investment within the UK has come from the software sector, largely driven by companies including Delcam, Granta, Materialise UK and Simpleware.

Figure 7 - Investment in AM R&D by supply chain position



University and RTO investment

In the UK AM research community (Universities and RTO's), £51.4M has been invested in R&D activities and £16.2M in technology transfer (2007–2016 time frame).

The UK within the EU

There are currently 20 active EU FP7 projects with work packages focused on Additive Manufacturing. A further 2 projects have finished in recent months, with one FP6 project dedicated to AM finishing in 2010. The current active FP7 projects are worth a

combined €99.3-million of public and private sector investment, of which €84-million relates directly to AM aligned work packages.

Of the 20 current projects, the UK leads nine projects (45%), this being more than any other country in Europe. Moreover, of the 240 partners engaged in collaborative AM projects around Europe at this time, 54 are UK based organizations, again representing the largest proportion of participants by any EU member state (23%).

One alternative to measuring financial input to research activity is to measure one of the outputs, namely, research publications. This allows us to identify a number of important metrics, including the locations of research critical mass, and the focus of research activity in terms of technologies and applications.

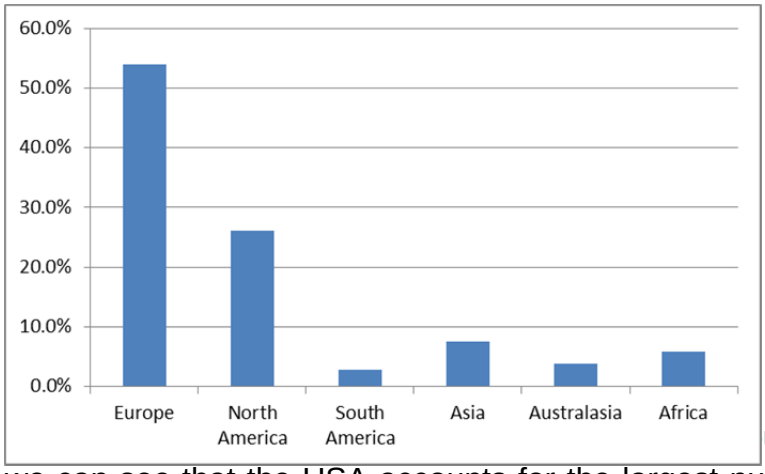
To undertake this review it was decided to focus on conference base publications. This decision was taken given the limited number of dedicated AM related journals and peer reviewed publication titles. A review was therefore undertaken of all AM related conferences taking place in 2011, including international conferences known to have sessions dedicated to AM activities. A list of the 17 conferences identified can be seen in Figure 8. From these conferences a review was undertaken of 495 individual papers or abstracts.

Figure 8 – List of AM related conferences

Conference	Location (Country)	Number of Papers	Conference focus
3DSUG	USA	24	AM & RP
AFPR	France	32	AM & RP
AMIC (Loughborough)	UK	20	AM
ICAT	Slovenia	42	AM
NZRPD	New Zealand	14	AM & RP
RAPDASA	South Africa	37	AM & RP
RapidTech	Germany	37	AM
RPDM	UK	17	AM & RP
RPS	Japan	18	AM & RP
SFF	USA	56	AM
SME Rapid	USA	51	AM & RP
TCT	UK	21	AM & RP
VRAP	Portugal	85	AM & VR
Wohlers	Germany	10	AM
DigiMan	USA	10-relevant	Digital printing
Powders AUS	Australia	8 - relevant	Powders
TENG	Japan	13 - relevant	Tissue engineering
		495 Total	

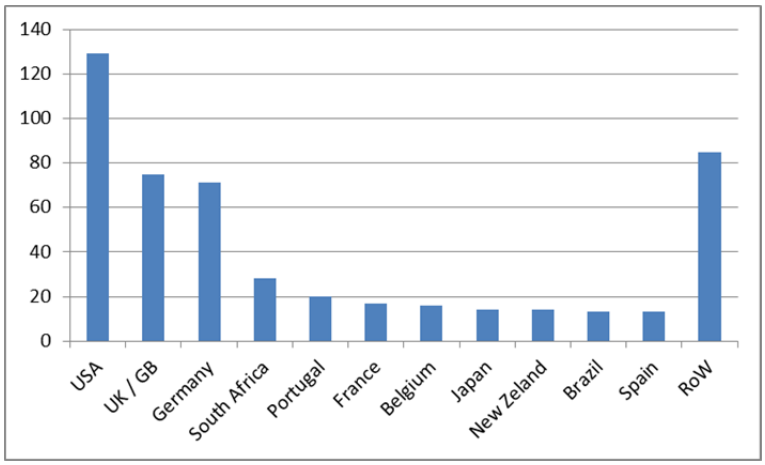
As shown in Figure 9, 54% of all Additive Layer Manufacturing conference papers were authored in the EU, with 26% authored in the USA and the remaining 20% authored in the rest of the world.

Figure 9 - Percentage distribution of AM conference papers by region



untry level, as shown in Figure 10, we can see that the USA accounts for the largest number of papers (129), followed by the UK (75) and then Germany (71).

Figure 10 - Number of AM conference papers by leading countries

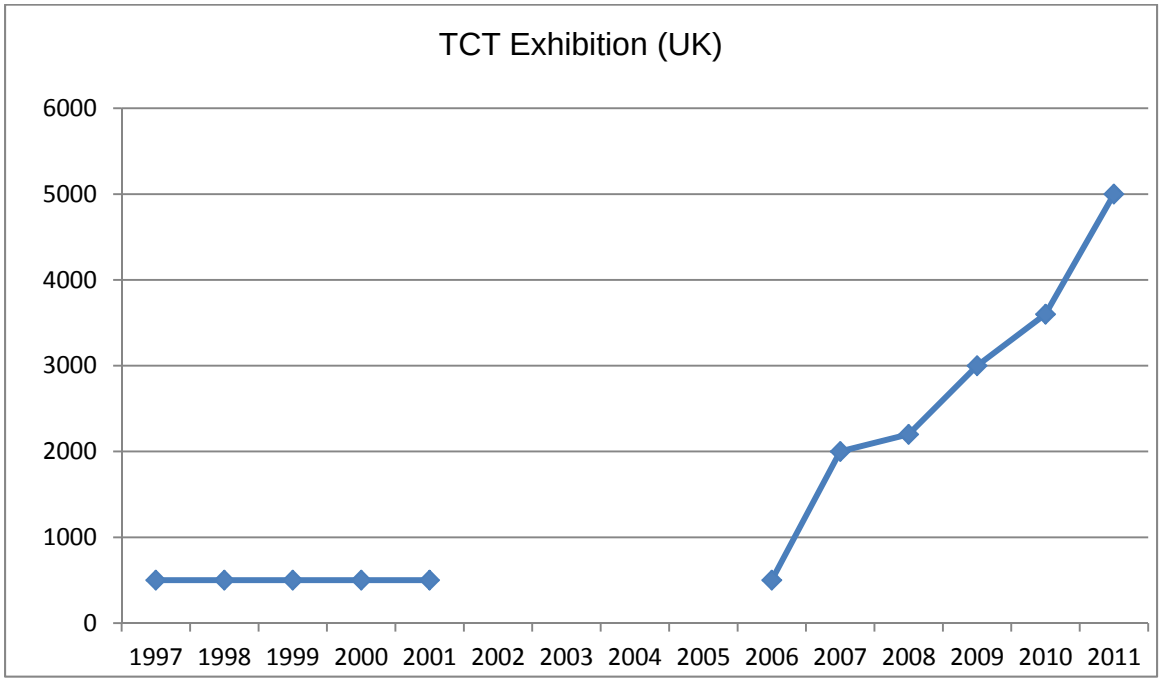


Of course, if we consider these statistics in terms of per capita population, we see a very different picture. Using 2010 World Bank data on population (USA = 311,591,917 / UK = 62,218,761 / Germany 81,702,329), we find that the UK produces 315% more AM related paper per capita than the USA, and 40% more than Germany. This would clearly suggest that the UK AM research community holds a prominent global position. It could of course be argued that UK conference focus on UK papers and presentation and therefore slew these results.

However, this is at odds with online usage of the Rapid Prototyping Journal. Between 2005 and 2011, (online) usage in the UK increased by 273% whereas for the same period, usage worldwide increased by 419% (and in the USA specifically this increase was higher at 426%).

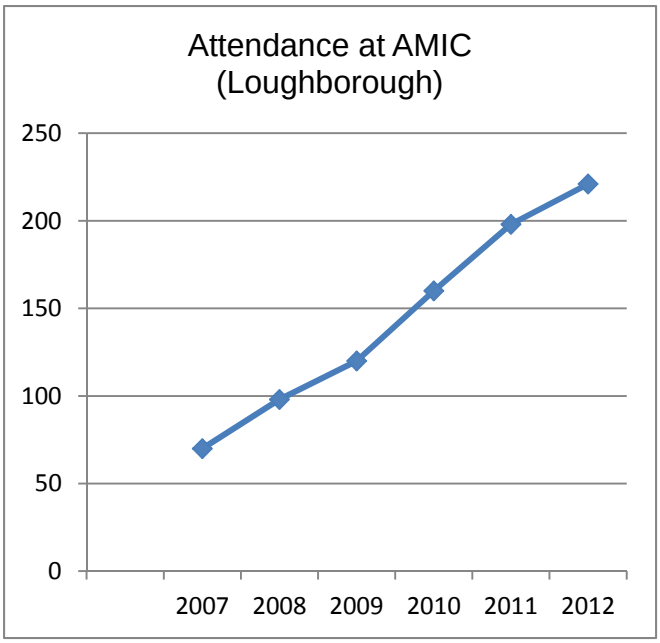
There has been a very strong growth in the numbers attending the TCT exhibition as shown in Figure 11. In the early years the emphasis was on the conference whereas later years concentrated on the exhibition.

Figure 11 TCT Exhibition Attendance



However, the attendance at Additive Manufacturing International Conference (AMIC) (Loughborough) has also increased as shown in Figure 12.

Figure 12 Attendance at AMIC



In summary, it can be concluded that the UK is unarguably one of the world's leading sources of AM related knowledge and research activity, along with Germany and the USA.

However, this now raises a number of questions such as:

- What education activities have taken place?
- How many people have been involved in receiving education and to what level?
- What benefit have these people obtained from the education?
- What benefit has there been to UK plc?
- Which education activities have provided the most benefit?
- Which education activities should we drop and which ones should we increase?
- Was all this knowledge creation worthwhile?

AM Education activities

The education regarding Additive Manufacturing in the UK really started in earnest during 1992. During this year there were a number of seminars and conferences including the 1st European Conference on Rapid Prototyping which was held at University of Nottingham.

During the past 20 years the education activities have included a variety of print media, television programmes, web sites, events, research projects, technology transfer, formal teaching etc. This work has been predominantly undertaken by universities, service bureaus, machine and material suppliers and media organisations. It would be very difficult to calculate the number of person years involved but it is likely that it would be a large number.

Examples of activities can be seen in Figure 13.

Print		**Examples**			
	Research Journals	Rapid Prototyping Journal			
	Magazines	Prototyping Technology International	Engineering Designer	Pro/E Magazine	CadDesk Magazine
		Precision Toolmaker	Castings Buyer	TCT	Economist
	Newspaper articles				
	Books				
Television		Tomorrows World	Life on Earth	Discovery Channel	Sky News
Online	**Web sites**	Machine sellers	Bureaus	Consultants	Casting companies
		University	Youtube		
Events	**Conferences**	European Conference on Rapid Prototyping 1992 -	National Conference on Rapid Prototyping & Tooling Research, 1995 to date	Loughborough Conference 2006 to date	TCT Conference 1996 to date
	Exhibitions	Mach	Celebration of UK Manufacturing (EPSRC)	Science Museum	TCT Live
	Seminars	IMechE Seminar on Rapid Prototyping Systems, 1992	DTI Seminar 1992	Rapid Prototyping & Manufacturing Association Seminar, 2001 -	Association of Laser Users

Ongoing Activities	**Research Projects**	EU	EPSRC	DTI/TSB	Dept of Health
	Technology Transfer Activities	1993 - Technology Transfer Centre for Rapid Prototyping, University of Nottingham	Rapid Manufacturing Consortium		
	Informing Stakeholders	TSB/BER/BIS Visits	H&S Visits	Foresight Team	
	University Courses	Masters Training Programme in Rapid Product Development.	Undergraduate courses (home and away)		
	Consulting Activities				
	Community Building	National Centre for AM			

Unfortunately there is very little information available on the number of people involved in the activities above. Even if information was kept at one time it has largely been lost. However, it is probably more important to quantify the benefit to individuals and here there is no real information. Therefore, it is not possible to determine what benefit has accrued to the UK economy, which activities have been most useful and would be in the future.

It is clear that there is real potential here for a research project to try and track this activity properly and the resulting benefits.

Acknowledgements

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