Intellectual Property Office

3D Printing
A patent overview

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Executive summary

3D printing is presently gaining lots of attention in the press as a new technology, but what does the technology landscape look like through a patent landscape analysis?

It is important to comprehend the fact that the term “3D printing” can be considered an umbrella term for a number of related technologies that can be used to produce 3D objects. The current dataset has attempted to combine these technologies to provide information about 3D printing itself from a macroscopic perspective.

The area of 3D printing has increased massively since 1980 (which constituted the date limitations of the current dataset). However, the fact that there is patent data from this era which is still relevant to this field of technology, is illustrative of the fact that this technology has existed in many forms for some time, and that it is only recently with advances in computing and software combined with large amounts of media interest, (plus the expiration of a number of useful patents) that has led to the current status regarding this technology.

A number of patents have been highlighted as being cited in other patents, perhaps providing an indication of the quality of the disclosures contained therein. There has been an increase in interest in this area, through an expansion of the numbers of academic papers, and increasing use of Internet search terms that can be related to 3D printing. Filings from the year 2000 onwards have demonstrated the largest increase in volume, despite the potential effects of the economic downturn in this time period.

The UK does not appear to have a degree of specialisation in this area from the current patent filings. The UK does perform better in terms of the location of the inventor rather than as a location for filing of the application or the country from which priority is taken.

Most of the top applicants are US based companies. However, many of the inventors are not US based, but file their patents in this location. It is also evident from the data that the top applicant holds many patents in the area, but that these are older than those from other top applicants and will expire soon.

A review of landscape maps of this technology reveals that key areas of interest include biomedical applications, circuits and electrode fabrication.

Future work could take many forms given the diversity of the technologies contained within the dataset. It would to interesting to look at Trade Mark filings in this area to see if there is a relationship between this data and the current patent data.

Further work would encompass the analysis of particular parts of this dataset to provide analysis of patent data relating to particular technology areas such as biotechnology. Future work would also be envisaged in performing a more complete analysis of trade mark data in this area as well as consideration of data available from journal and conference proceedings.

The issue of intellectual property and 3D printing has not been fully considered in the current report but it remains an important issue in this field that is ripe for further consideration

One commentator (Basiliere) put it well, in that he stated that consumer 3D printing is at the "peak of the hype cycle" It is difficult to determine if this comment is really true. However it is evident from the information in this report, that 3D printing is spreading across many technologies and has the potential to disrupt many of them..

Contents

1 Introduction

3D printing[1] is creating interest due to its potential to be a ‘disruptive technology’ and the effects this could have on traditional manufacturing and business methods as well as the legal implications for intellectual property rights. This seeks to examine the current status of the technology as reflected by IP rights. It does not aim to examine the implications of 3-D printing technology for the current IP right framework but provides a contribution and backdrop to such ongoing debates. A representation of the increased degree of interest that has been shown in this technology is illustrated by the graph shown below which plots the number of searches done through the use of Google® over time.

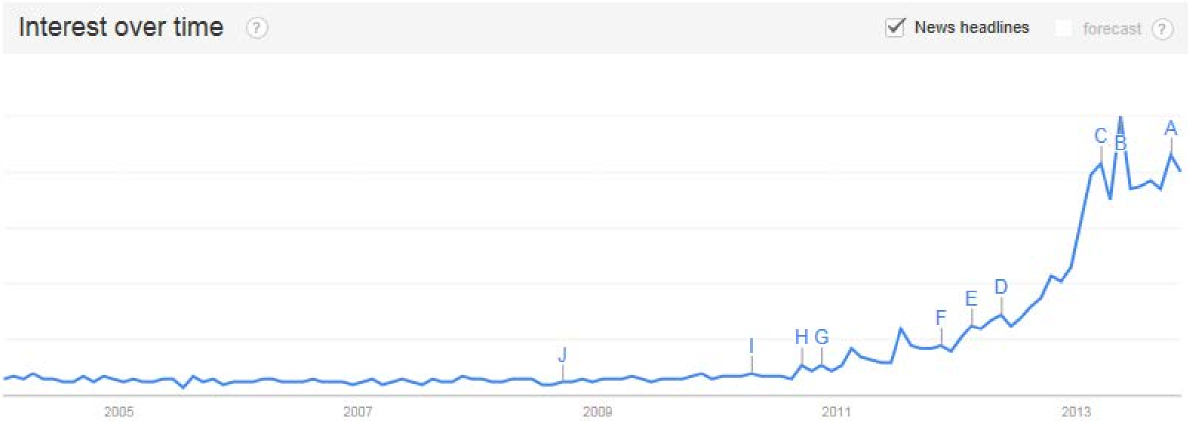

Figure 1: Plot of number of times that the search term "3D printing" has been inputted in to the search engine Google. The letters refer to the co-occurrence of news articles

The recent media interest might give the impression that it’s a brand new technology, which is not generally the case. The technology which underpins 3D printing is not new and the term is more of an umbrella term, as it incorporates a number of different, known technologies within its ambit..

It is also known as “additive manufacturing” and involves "printing" items in various materials such as plastic, metal or wax by adding small amounts of the material until a completed three-dimensional product is formed.

3D printing differs from typical mould or cast manufacturing. A digital image is created using a CAD (computer aided design) file which is used to ‘print’ the object layer by layer using a mixture of inks and additives ranging from plastics to metals and specially developed clays depending on what the end product is. It is more efficient than traditional methods because there are fewer waste materials than with moulds or casts thus satisfying concerns about environmental issues and the overall impact of the technology. A TV news item demonstrated how a model of the presenter’s head taken from a photograph was built during the duration of the programme. [2]

The ability to ‘print’ objects on demand could change how and where manufacturing takes place and the type of facilities required. This could lead to a shift from mass production to more local

[1] The Google trends facility is available here: https://www.google.co.uk/trends/explore#q=3D%20printing&cmpt=q
[2] http://www.bbc.co.uk/news/science-environment-20130762

production, nearer to the end user's market. This has the potential to allow expansion of smaller and medium sized developers and investors as costs of 3D printers become more affordable. However costs of the necessary additives such as titanium powder are high and knowledge of CAD type programs may be required. Amazon® is selling 3D printers and supplies; Ebay® has also launched a service called Exact which allows users to purchase devices from 3D printing companies via a mobile device. Typically from order to receipt the timeline is 7-14 days. A US company MakerBot® which merged with Stratsys in August[3] are one of the largest manufacturers of 3D printers; their CEO described them as the 'beginning of the next industrial revolution'. Laboratories (i.e. Fablabs) are being set up in US and UK to enable creators with ideas to test out their designs.

3D printing is likely to have an impact on the healthcare industry because of the ability to manufacture prosthetics and implants specifically designed for the patient by using CT or MRI scan data. Replacement splints[4] and a robotic hand are amongst the items manufactured using 3D printing. Researchers at Harvard School of Engineering and Applied Sciences 3D printed layers of stacked electrodes each less than the width of a human hair to produce lithium-ion micro batteries smaller than the size of a grain of sand.[5] This would be a big step forward for applications from medicine to communications, where standard sized batteries would have proved too big to fit small devices but would store enough energy to work them.

Microsoft® has developed a technology called 'infraStructs'[6] these are tags embedded inside 3D printed objects which relay the information stored in them to a scanner, for instance, price barcodes. However the option for hiding encoded information for more complex intelligence purposes exists with this system. Illegal copies of US State department guns were produced following mass copying of design files, legal talks ensued following this violation of international weapons law. Concerns raised on health issues related to 3D printing at home, due to emissions in inadequately ventilated areas[7].

Some large toy manufacturers use 3D printing as a more efficient way of producing their lines. Car manufacturers are investigating production of auto parts and the aerospace industry[8] is already producing lighter aircraft engine parts which will lead to fuel cost savings. Trainers and footwear made by 3D printing methods would be lighter and more flexible so enhancing the wearer's performance. NASA is interested in using 3D printing to create food for astronauts. It is considered that pizza could easily be produced on a 3D printer due to the distinct layers. NASA is also preparing to launch a 3D printer into space next year, enabling astronauts to manufacture spare parts, tools and supplies[9]. In the UK Vince Cable, Secretary of State for Business, Innovation and Skills announced a £14.7 million investment in the UK's 3D printing industry and collaboration with the Technology Strategy Board to increase economic growth in the UK manufacturing sector[10]. There is also currently an exhibition at the Science Museum in the UK about 3D printing[11].

At present printers work quite slowly, so it is thought that for mass production traditional methods will remain, however the market for smaller batches and individual items is likely to be in high

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3 http://www.makerbot.com/blog/2013/08/15/makerbot-and-stratasys-merger-closing-2/
4 http://www.independent.co.uk/life-style/health-and-families/health-news/splint-made-by-3d-printer-used-to-save-babys-life-8627590.html
5 https://www.seas.harvard.edu/news/2013/06/printing-tiny-batteries
6 http://www.vcpost.com/articles/12259/20130727/microsoft-enters-3d-printing-industry-infrastructs.htm
7 http://phys.org/news/2013-07-3d-printers-shown-emit-potentially.html
8 http://www.gereports.com/ge-started-testing-next-gen-jet-engine-with-3d-printed-parts/
9 http://www.bbc.co.uk/news/technology-24329296
10 https://www.gov.uk/government/news/147-million-boost-for-innovative-3d-printing-projects
11 The exhibition is sponsored by many of the companies and academic institutions involved in 3D printing. A link to the relevant website is provided here:
http://www.sciencemuseum.org.uk/visitmuseum/plan_your_visit/exhibitions/3d_printing_the_future.aspx?gclid=CPuFo5fN3LoCFfSWtAodLRQAiw

demand. According to the Wohlers report[12] the growth of the area of personal printers has increased on average 346% each year from 2008 to 2011, with the source of most of this growth from a single open-source project run by the University of Bath, UK[13]. This is illustrated by another plot of media interest from Google Trends, as shown in Figure 2.

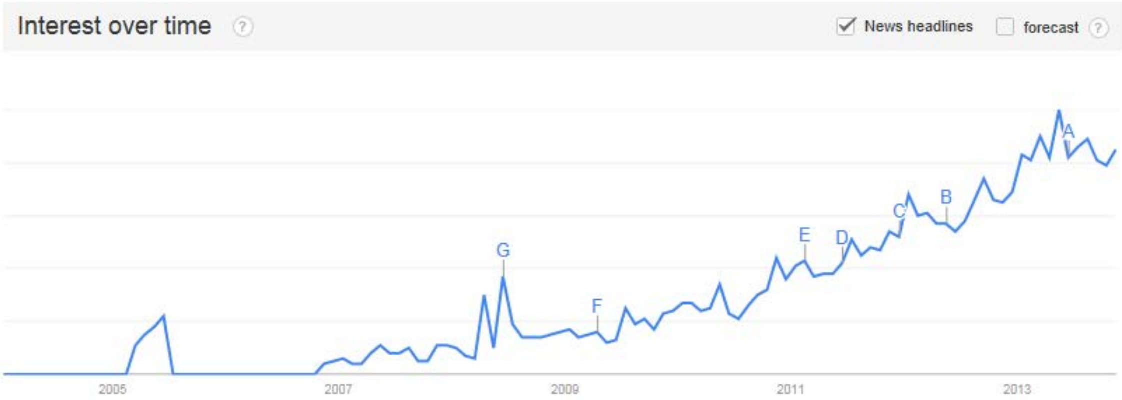

Figure 2: Plot of number of times that the search term "Reprap" has been inputted in to the search engine Google. The letters refer to the co-occurrence of news articles[14]

So what does the future hold? The next step would be 4D printing where 3D printed items containing programmable cell molecules could change and evolve depending upon the programming[15,16].

Consequently, in the context of this rapidly developing technology area, the current study has been performed looking at a dataset comprising a large number of individual patents and analysed to give a macroscopic view of this technology "space" over time. A full description of the search performed is in Annex A.4 although it is noted that the outcomes of a recent CPC (Co-operative Patent Classification) working group may result in the revision of the classification system with a specific marker similar to that for nanotechnology being proposed, and hopefully soon to be highlighted[17,18].

A search of Non-Patent Literature (NPL) data has also been performed to place the current dataset in context. NPL data consists of Open Access Journal publications and conference proceedings[19]

[12] Wohlers report 2013 , Additive Manufacturing and 3D Printing State of the Industry, Wohlers Associates 2013, available from: http://wohlersassociates.com/2013report.htm

[13] The Reprap project was set up at the University of Bath, more information is available from: http://reprap.org/wiki/RepRap

[14] The Google trends facility is available here: https://www.google.co.uk/trends/explore#q=reprap&cmpt=q

[15] http://www.bbc.co.uk/news/technology-21614176

[16] http://www.dailymail.co.uk/sciencetech/article-2440233/The-rise-4D-printing-From-self-assembling-furniture-camouflage-changing-tanks-U-S-Army-latest-group-develop-morphing-materials.html

[17] RP0015 project on additive manufacturing http://www.cooperativepatentclassification.org/CPCRevisions/Projects.html

[18] Discussion regarding this issue have been subject to a number of classification meetings, a full notice regarding these proposed changes is likely to be published in the near future here: http://www.cooperativepatentclassification.org/CPCRevisions/NoticeOfChanges.html Furthermore there is also a change proposed involving the move of B29C67/0051 to the new main group B29C64/00 for plastics additive manufacturing only, (the subgroups will also move)

[19] Details of the coverage of NPL is given here: http://thomsonreuters.com/web-of-science However, the content covers over 150,000 conference proceedings and 12,000 high impact journals and open access journals from 1900

Further details concerning the search of NPL and the patent search are provided in Appendix B, and a quick review of trade marks in this area has also been executed given the extensive interest in this technology by the retail sector. Further information on the search that was performed is available in Appendix B. The combination of freely available public data, whether it be IP, academic or internet based information should serve to shed some further light on this rapidly developing subject area.

2 Worldwide patent analysis

2.1 Overview

Table 1 gives a summary of the extracted and cleaned dataset used for this analysis. All of the analysis undertaken in this report was undertaken on this dataset or a subset of this dataset. The worldwide dataset for published 3D printing patents contains about 9100 published patents equating to over 4000 patent families. A patent family is a group of patents relating a similar invention. Analysis by patent family more accurately reflects the number of inventions present because generally, there is one invention per patent family, whereas analysis by raw number of patent publications inevitably involves double counting because one patent family may contain dozens of patent publications if the applicant files for the same invention in more than one country. Hence, analysis by patent family gives more accurate results regarding the level of innovation taking place.

Table 1: Summary of worldwide patent dataset for 3D printing

Number of patent families		**4015**	
Number of patent publications		**9145**	
Publication year range		**1980-2013**	
Peak publication year		**2012**	
Top patent issuing country		**US**	
Top inventor country		**US**	
Top inventor		**James F Bredt**	
Top patent assignee		**Fujitsu**	
Field choices	**Field name**	**Number of entries**	**Coverage**
People	**Inventors (cleaned)**	**8500**	**98%**
Applicants	**Patent Assignees (cleaned)**	**3978**	**99%**
Applicant country	**Applicant country**	**58**	**100%**
Countries	**Publication country**	**49**	**100%**
Years	**Publication year**	**33**	**100%**

The current dataset has been reduced from a much larger one to concentrate on the concept of 3D printing in the modern sense[20]. This in itself is evidence that the underlying principles which enable this technology have been known for some time so that much in this technology area represents incremental changes rather than single “breakthrough” inventions. From Table 1 it is evident that patenting in this technology is established; and that further development is still occurring.

This evidence is borne out by the content of the graph in Figure 3. This graph has been abbreviated, as the data that is present regarding 2013 has not been included as it is incomplete for the year, and appears misleading when included on such a graph. The data extends to encompass the content of patents from the 1980s[21]; however, given that a patent lasts for a maximum of 20 years the content of these patents, if granted, is no longer protected. The figure demonstrates that there has been a big increase in the number of patents filed starting in about the year 2000. This interest still appears to be escalating, while media coverage (note Figure 1 and Figure 2) has increased.

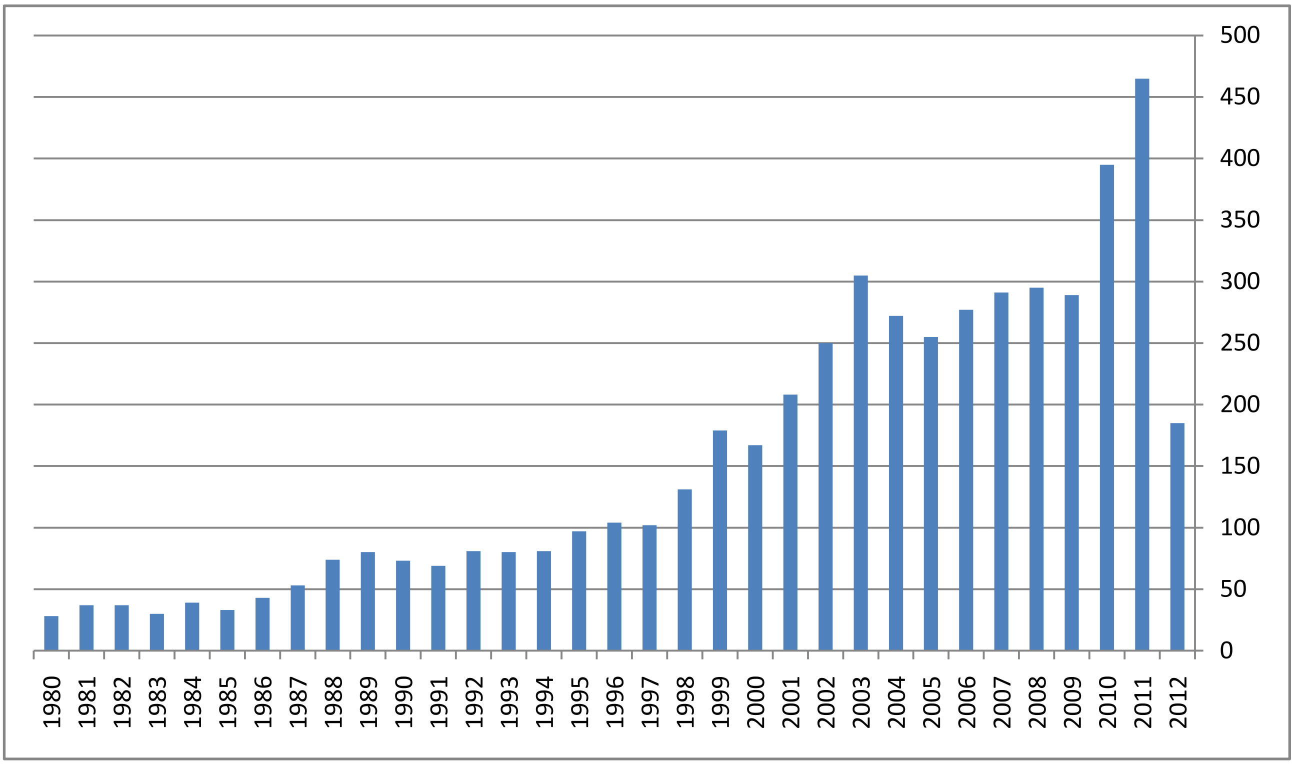

Figure 3: Patent priority applications by priority year

However, it is important to note that Figure 3 shows only patent applications, it is not representative of patents that have been granted and may therefore be in force. It is also important to note that the data for 2012 is not yet complete due to the fact that there is an 18month delay before patent applications are published, .As is notable from Figure 4 the number of granted patents is generally much smaller than those applied for. It should also be noted that the scope of protection applied for may differ substantially from that granted.

[20]This refining of the original dataset is described in more detail in Appendix B
[21] This is substantiated by many media articles, such as the following article from Chris Notter, published in Oct 2013 The limits of 3D printing, The Deal, available from: http://www.thedeal.com/content/industrials/the-limits-of-3d-printing.php

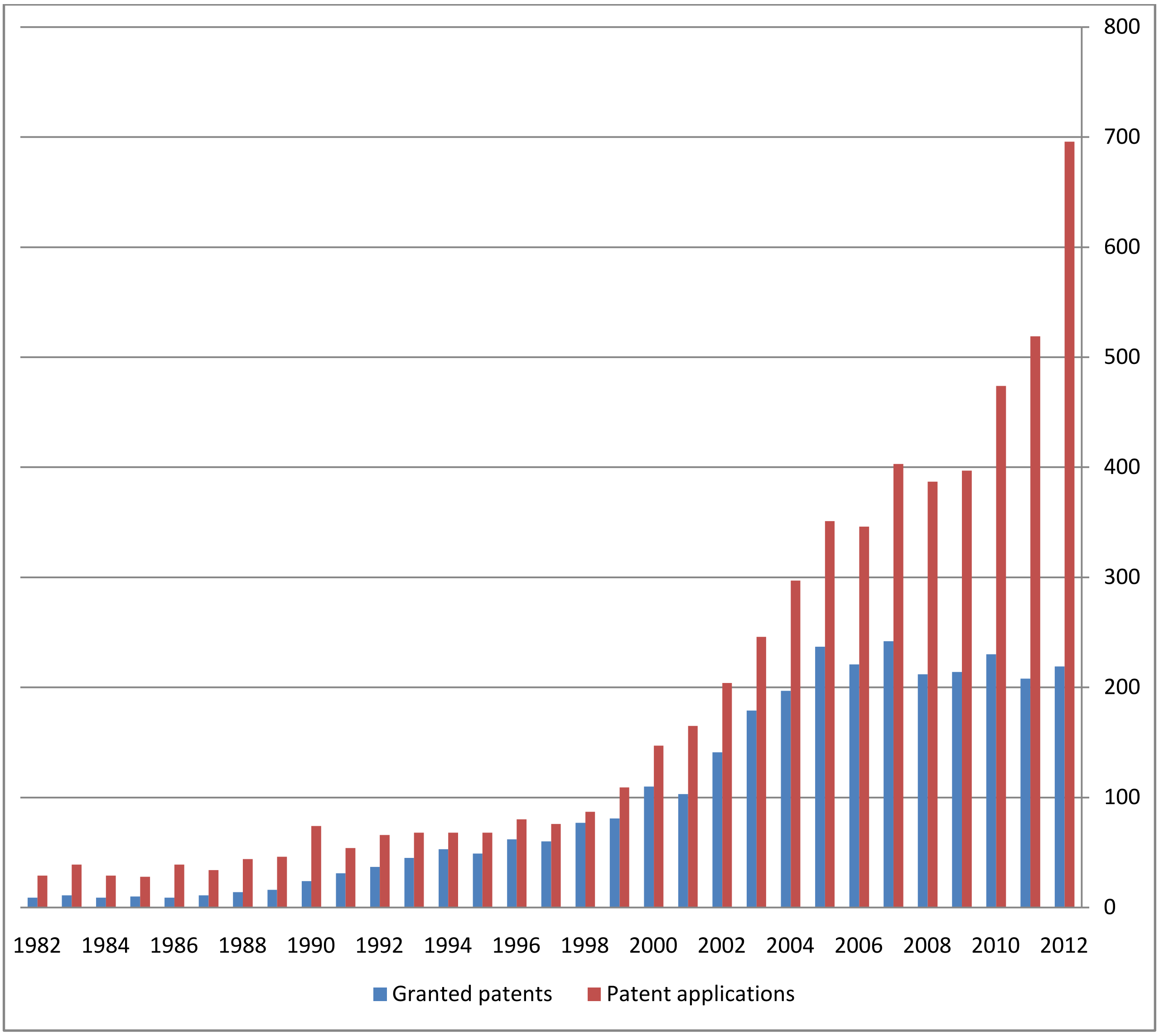

Figure 4: Comparison of granted patents and published patents applications by publication year

The plot shown in Figure 4 further demonstrates the point regarding the differences in numbers of patents granted and those applied for. Most patents are published without any presumption of whether or not a patent may be granted based on that application. Therefore solely looking at numbers of patent applications may not necessarily provide the degree of information required about a particular technology area. Some of these applications may also fall in excluded fields i.e. ones where no patent is allowable. In the UK there are a number of these fields such as business methods and presentation of information[22] and some of these excluded fields overlap with the technology area at hand. These include; business methods, computer software and medical methods of operation. This means that the number of patents issued in the UK may differ from those issued on other jurisdictions such as the US which does not have the same exclusions.

This figure illustrates the total number of published patent families by priority year (an indicator of when the original innovation happened) and the number of granted patents in the same priority

[22] These fields are set out in the Manual of Patent Practice (MoPP) available online at: http://www.ipo.gov.uk/pro-types/pro-patent/p-law/p-manual/p-manual-practice.htm (last accessed 15/10/13).

year. For example, a patent family with a priority date of 12 November 2002 will appear in the blue 2002 bar once it is published (approximately 18 months after the priority date) and then if a member of this patent family is granted at a later date (*e.g.* in 2006) then it will appear in the red 2006 bar once it is granted. *Data is considered to be incomplete for 2013 and so has not been included in the plot.*

This diagram requires some clarification in that the difference between the blue and red bars does not only represent unsuccessful patent applications, as there are a number of reasons why a patent may not reach the grant stage. The primary reason is due to the filing strategies of the applicant. The applicant may file more patents than they ever intended to reach grant. There is also a delay between the publishing of an application and the granting of a patent. This time delay tends to vary according to patent office but can usually be calculated in years. This then means that the numbers represented by the blue bar in Figure 4 may not be useful in determining the current trends relating to patents and a particular subject area. It also explains the reduction in patent grants and publications towards the more recent year. It is for this reason that the data from 2013 has not been included in this plot as it is as yet, incomplete.

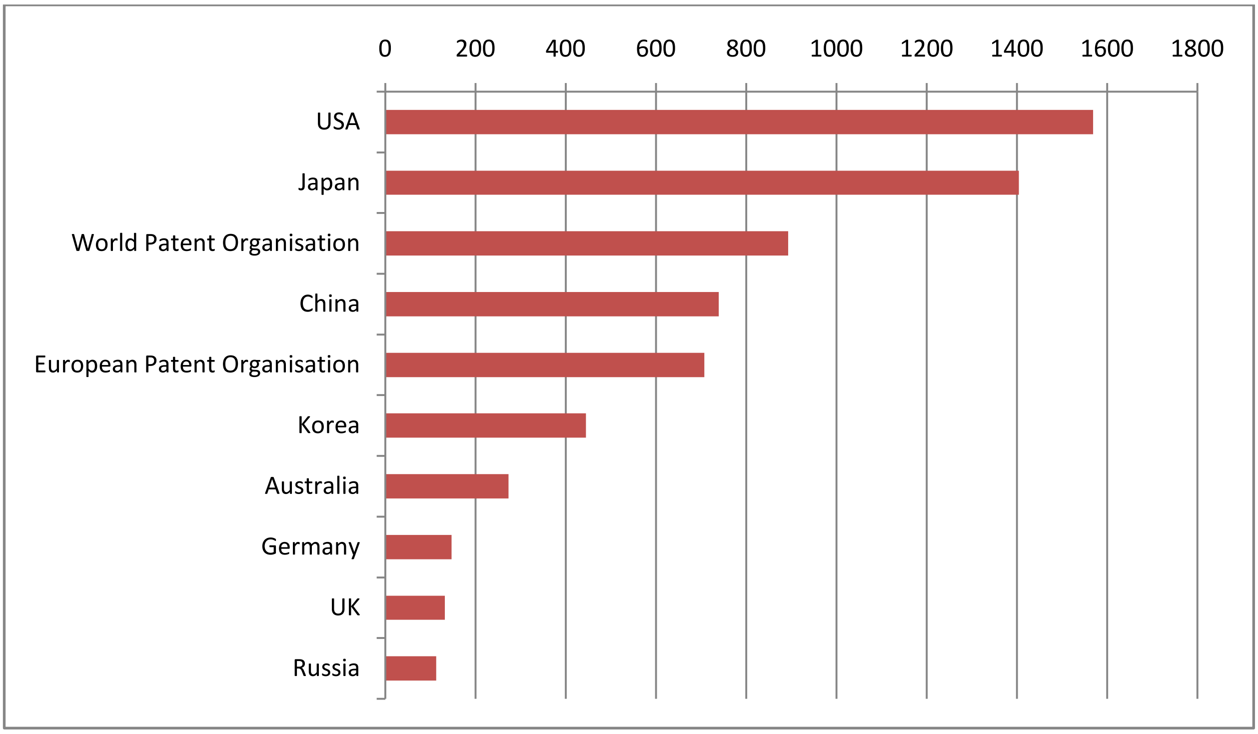

Figure 5: Publication country distribution for the top countries

Figure 5 shows a plot of publication country against volume of patent filings. It is easy to see that the US comes first in terms of sheer volume of filings. However, plain volumes of patent filings do not necessarily mean that the research which led to the filing of the patent originated in that location. This is especially true of large multinational corporations where the research labs may be located in a different country to the Head office, and yet it is the Head office address that is used to file all the patent applications. Figure 6 shows the equivalent plot for priority country. The order of the filings in terms of volume has not substantially changed. However, it is interesting to note that the UK performs better, in terms of location of priority country, rather than publication country. This may be due to the UK being used as a location for filing priority applications due to the speedy turnaround associated with UK patent searches; providing an indication if the patent application is worth pursuing. If so, it can then be used as a priority document to file elsewhere such as via the

European route. This may also explain the relatively low ranking of EP (European) patent applications in terms of the top ten priority locations relative to the UK (GB).

Very generally speaking, priority country analysis is a reasonable indication of where the innovation is actually taking place because most applicants will file first in the country in which they reside[23]. This is particularly the case where the dataset is not dominated by large multinationals. As noted earlier, the fact that software can be patented in the US may also have an influence on the priority country of the patent filing.

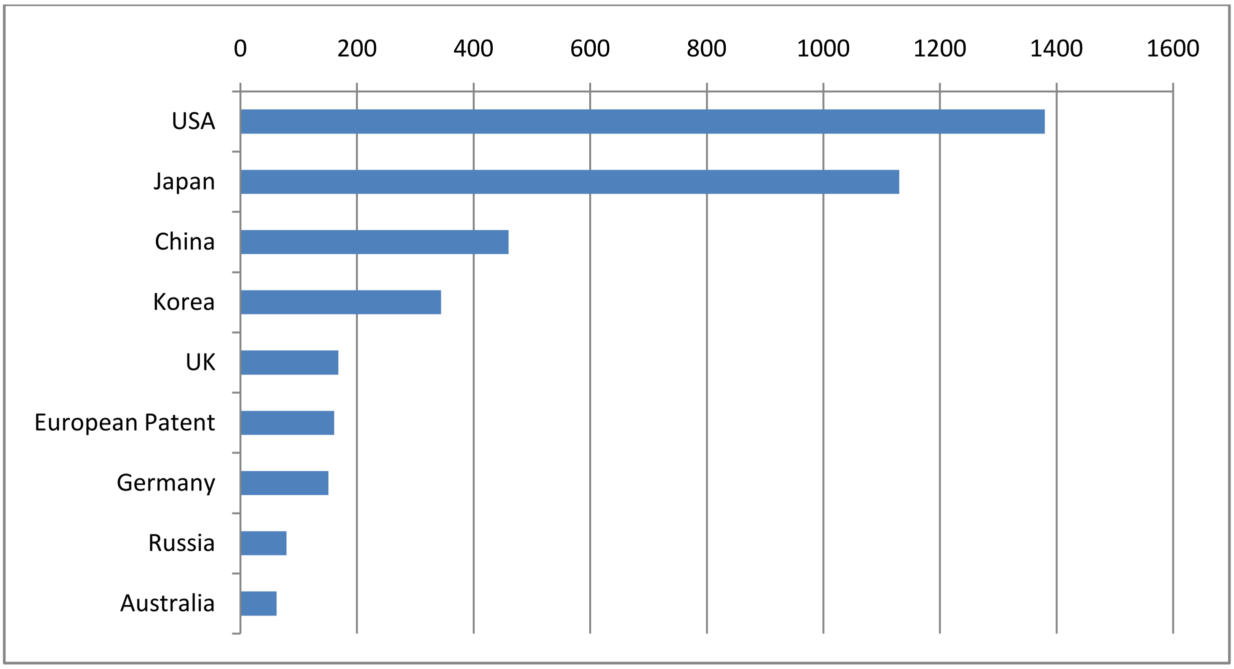

Figure 6: Priority country distribution for the top countries

However, it is well known that there is a greater propensity to patent in certain countries than others, and the trends shown in Figure 6 may change if the figures are corrected for this difference in behaviour. Therefore, the Relative Specialisation Index (RSI)[24] for each applicant country has been calculated to give an indication of the level of invention in 3D printing for each country compared to the overall level of invention in that country, and is shown in Figure 7.

The RSI values shown in Figure 7 show that the UK has a negative RSI i.e. that it specialises less in this area compared to other listed countries with a positive RSI.

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[23] In some countries this is/was a requirement (*e.g.* in the UK this was a requirement until 2005).
[24] See Appendix C for full details of how the Relative Specialisation Index is calculated.

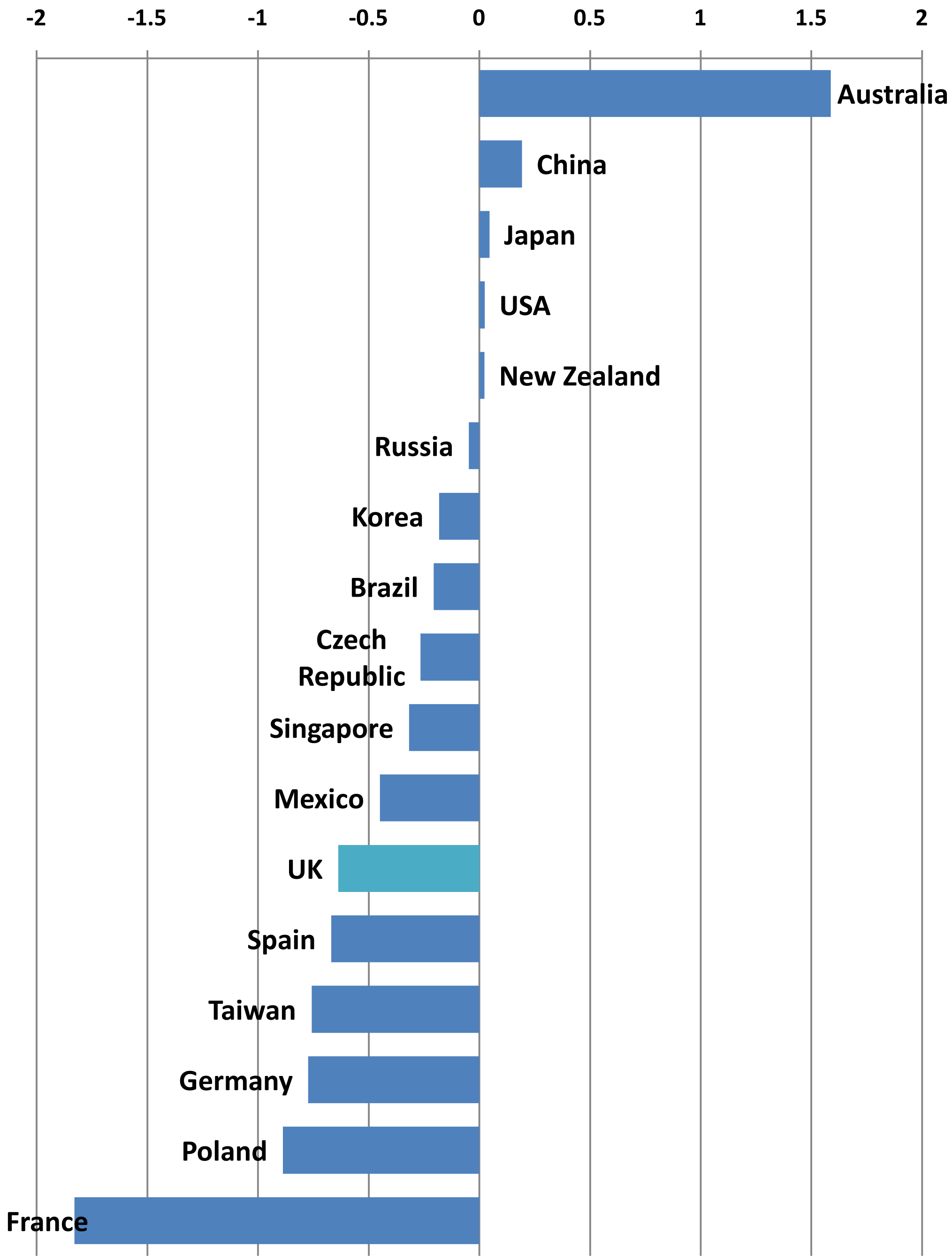

Figure 7: Relative Specalisation Index (RSI) for the top filing patent countries

The plot of RSI value shows Australia at the top of the graph with a high degree of specialisation in this. This can be accounted for by the efforts of a single inventor, Kia Silverbrook who has since gone on to found his own series of companies based on this technology. Silverbrook filed many patents and is known as the most "prolific inventor in the world"[25] and his companies[26] still perform much research around the world. His patent applications are not restricted to a single area of

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25 http://www.patent-rank.com/news-blog/kia-silverbrook/2013_04_29/
26 One of his companies performs scientific research in many disciplines. It's website is available here: http://www.silverbrookresearch.com/

technology but span many areas: video and audio production, computer graphics, digital printing, liquid crystal displays (LCDs), genetic analysis, molecular electronics, photovoltaic solar cells amongst others.

It is interesting to note that the Czech Republic comes out on the RSI plot shown in Figure 7 a country with a negative RSI, which still means that it is less specialised than the other countries listed with a positive RSI but it is less negative then the value assigned to the UK. This is interesting as when the Google trends® search engine was being reviewed for relevant searches to 3D printing (Reprap) this country came up as an area that had regularly searched using Google for these relevant search terms. This is perhaps generally summarised in Figure 8.

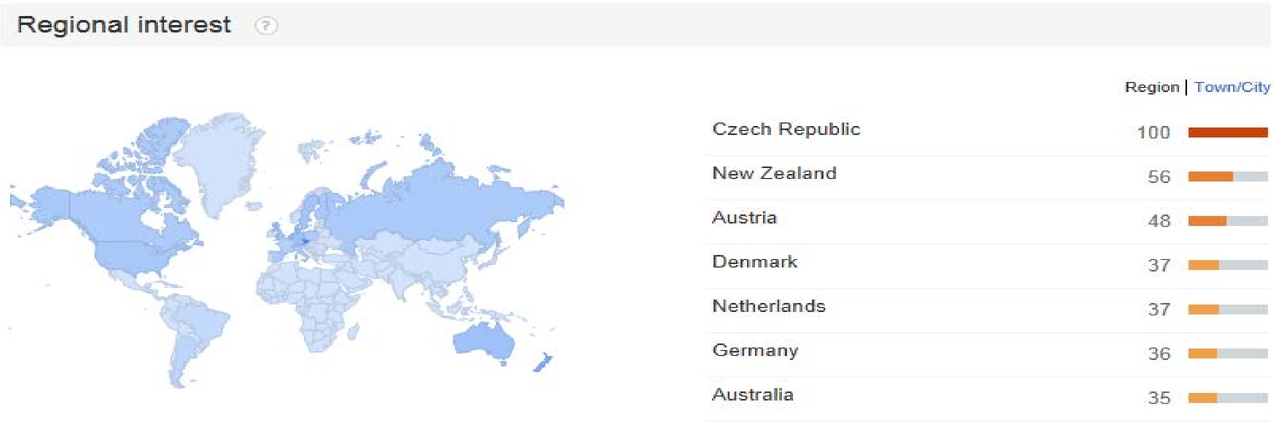

Figure 8: Google Trends search for Reprap showing Czech Republic interest

2.2 Top assignees

Looking at the top patent assignees[27] in the dataset, the company that comes out top is Fujitsu

Figure 9 shows that some of the top applicants, such as Fujitsu and NEC, have been involved in the patenting of 3D printing related technology for over 20 years. In contrast, some of the other top applicants, such as Stratsys and Corp Z, have filed for patents in this area only relatively recently. Thus this figure also shows when certain applicants have entered the technology space (*e.g.* Objet Geometries since 1989) and others have stopped patenting in the field (*e.g.* LG Phillips after 2004).

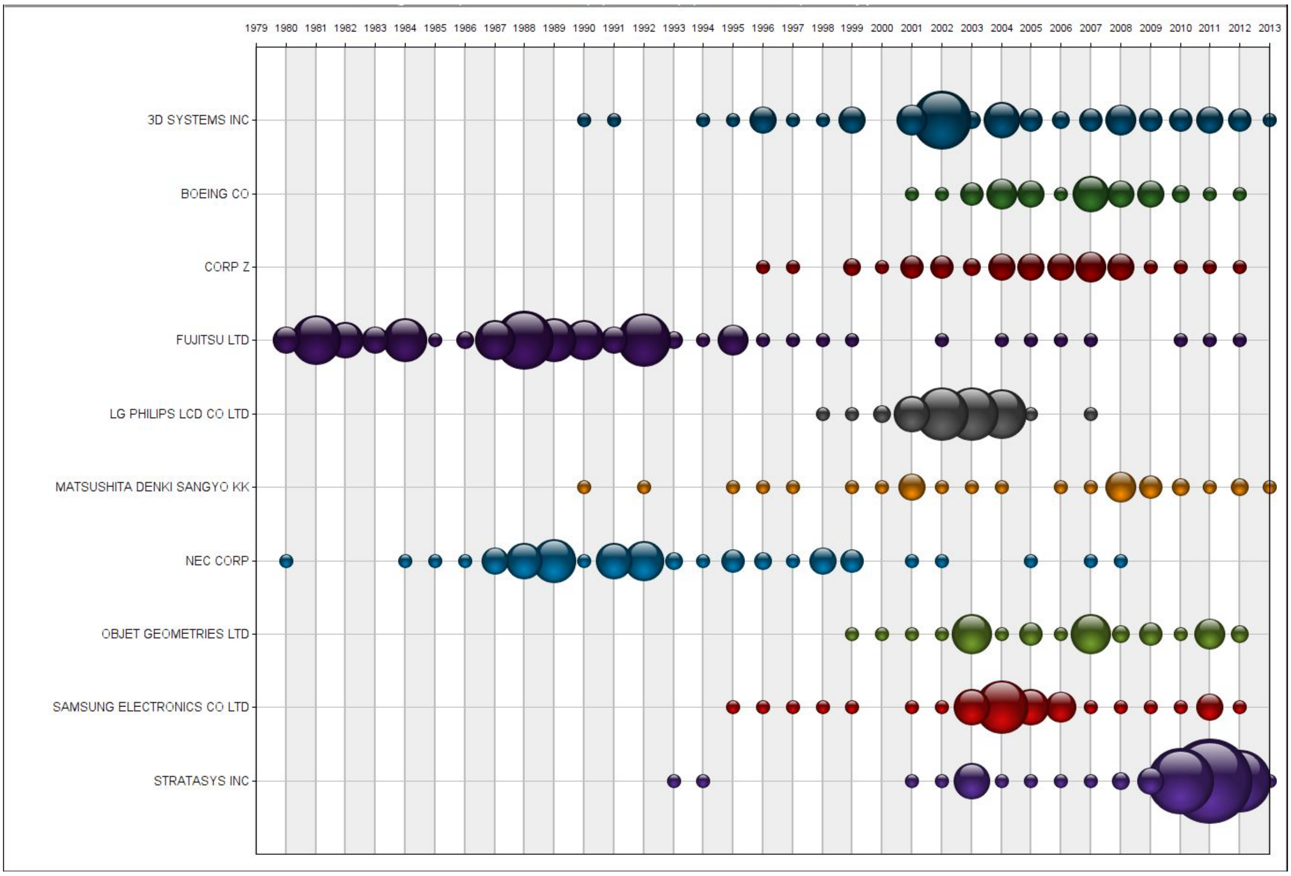

Figure 9: Bubble chart representing top patent assignee activity by year

However, on closer analysis of the data it is evident that this company (Fujitsu) has not been active in this area for some time and that the granted patents owned by Fujitsu will soon expire. This is illustrated by the rash of activity evident in Figure 9 for Fujitsu[28] in the early part of the timeline of the dataset. Many of these patents, if granted, will be coming towards the end of their monopoly status. If other members of this group of companies are compared, it is obvious that many of these companies are relatively new in the technology. This highlights the fact that the leading applicants in this area are not all US companies despite the fact that the US dominates the patent filing country in this technology.

[27] See Appendix A for further explanation
[28] Available from: http://www.fujitsu.com/global/news/pr/archives/month/2013/20131023-01.html

Interestingly, Fujitsu have just announced their new move in the 3D printing market: "Services will be offered in the following three fields:

(1) Fabrication of precision components

.. Fujitsu will accept orders to produce precision components, including highly complex components, such as those used in satellites and automobiles.

(2) Building prototypes using 3D printers

.. Fujitsu will produce prototypes using 3D printers, and not just from 3D data but from two-dimensional engineering drawings, or even hand-drawn pictures.

(3) Services to support production of customer products at Fujitsu's production facilities"

Both Stratasys and 3D systems did not apply for any patent until 1993 and 1990 respectively. Stratasys[29] did not start up until 1989 and was floated on the stock market in 1994. 3D Systems was founded in 1986 with a rapid acquisition process that initiated in 2011[30] as mentioned earlier.

Another point worth noting is that Stratsys[31] has merged with Objet[32] and MakerBot Industries[33] so that the patents owned by both these companies[34] will soon transfer to a single company which will certainly rank amongst the highest in this dataset. Similarly, 3D Systems[35] has also merged with Z Corp[36], and Vidar [37]systems amongst others. These have not been grouped together in Figure 10 but an illustrative table (Table 2: Top patent assignees after adjustment to take account of major company mergershas included these changes.

Stratasys' purchase of MakerBot highlights a recent spate of acquisitions as companies pursue the many areas of 3D printing. Crowd-sourced start-ups are appearing ever more regularly in this field[38].

It has been reported that both "Stratasys and 3D Systems have been the leaders in consolidation." and that 3D Systems has also made acquisitions, buying close to 40 targets since 2009.

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[29] Stratasys, Inc. History provided by Funding Universe, Available from: http://www.fundinguniverse.com/company-histories/stratasys-inc-history/ last accessed (15/10/13)
[30] 3D Systems: One stock, Two Perspectives, Forbes, Rakesh Sharma, Sept 2013. Available from: http://www.forbes.com/sites/rakeshsharma/2013/09/17/3d-systems-one-stock-two-perspectives/
[31] More information is available from http://www.stratasys.com/
[32] More information is available from http://www.compositesworld.com/suppliers/objet
[33] Stratasys Acquiring MakerBot In $403M Deal, Combined Company Will Likely Dominate 3D Printing Industry Posted Jun 19, 2013 by Darrell Etherington Available from http://techcrunch.com/2013/06/19/stratasys-acquiring-makerbot-combined-company-will-likely-dominate-3d-printing-industry/
[34] More details of mergers in this area: http://www.tctmagazine.com/additive-manufacturing/stratasys-vs-3d-systems%3A-a-heavyweight-fight%3F/ from TCT magazine, Rose Brooke 2013
[35] More information is available from: http://www.3dsystems.com/
[36] More information is available from: http://www.zcorp.com/en/home.aspx
[37] More information is available from http://www.vidar.com/
[38] Evidence for this phenomenon is given through the following links: http://www.kickstarter.com/projects/117421627/the-peachy-printer-the-first-100-3d-printer-and-sc
http://techcitynews.com/2013/08/28/balderton-capital-backs-crowdsourced-3d-printing-network-3d-hubs/
http://www.crowdsourcing.org/editorial/disruptive-influences-crowdsourcing-and-the-3d-printing-revolution/13865/related

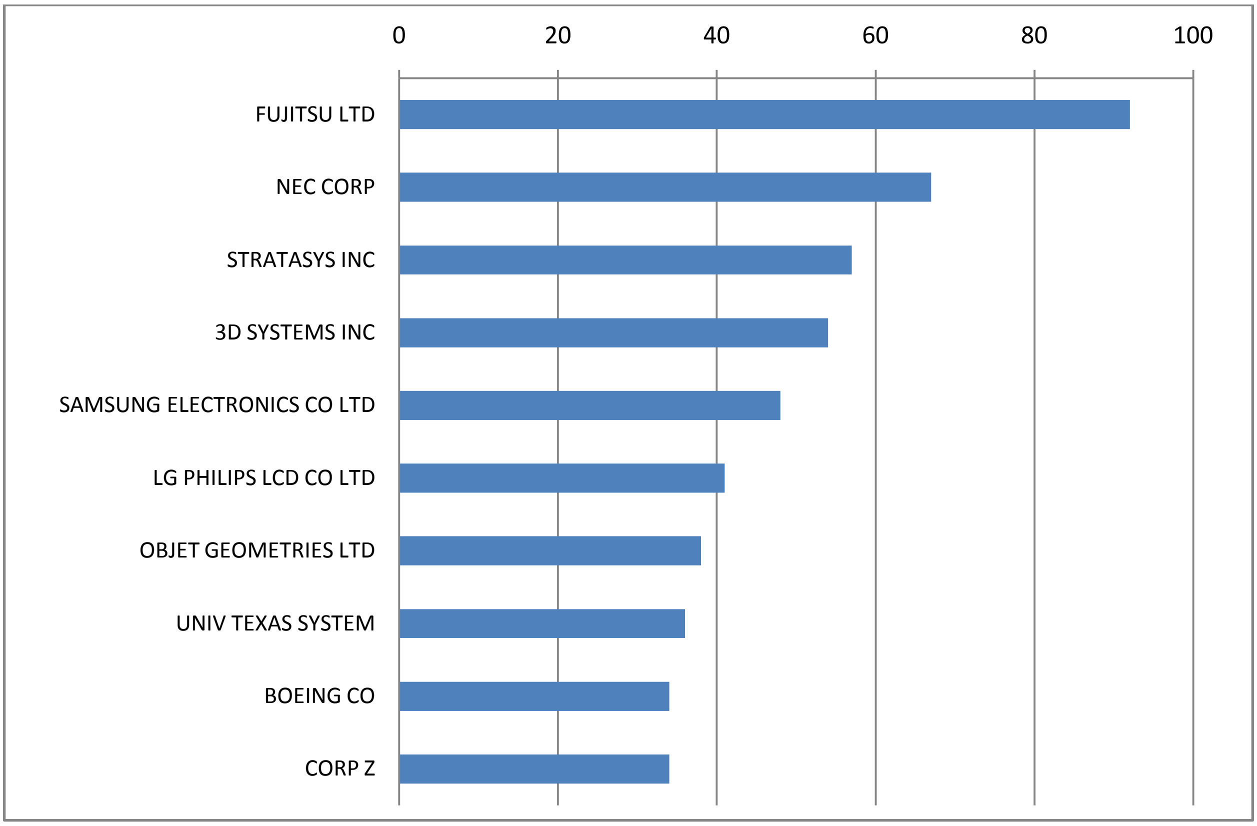

Figure 10: Top patent assignees families

Once all the figures have been taken into account in this area, it is evident that there is very little between the major players in this technology as the top three applicants all have the almost exactly the same number of patents. How successful a company may be is not dependent on the number of patents or indeed the quality of those patents, but using this source of information does provide an insight into elements that may form part of a successful company.

Table 2: Top patent assignees after adjustment to take account of major company mergers

Patent Assignees	Published Patents
Fujitsu Ltd	92
Stratasys Inc	92
3D Systems Inc	91
NEC Corp	67
Samsung Electronics Co Ltd	48
LG Philips LCD Co Ltd	41
Objet Geometries Ltd	38
Univ Texas System	36

2.3 Collaboration

These mergers are also indicated by a quick look at the top ten patent assignees and the patents that they hold jointly. This is shown in Figure 11. This figure represents a collaboration map showing all collaborations between the top applicants in the dataset (those shown in Figure 10) and their collaborators. Each dot on the collaboration map represents a patent family and two applicants are linked together if they are named as joint applicants on a patent application. A collaboration map can be a good indicator of technology transfer.

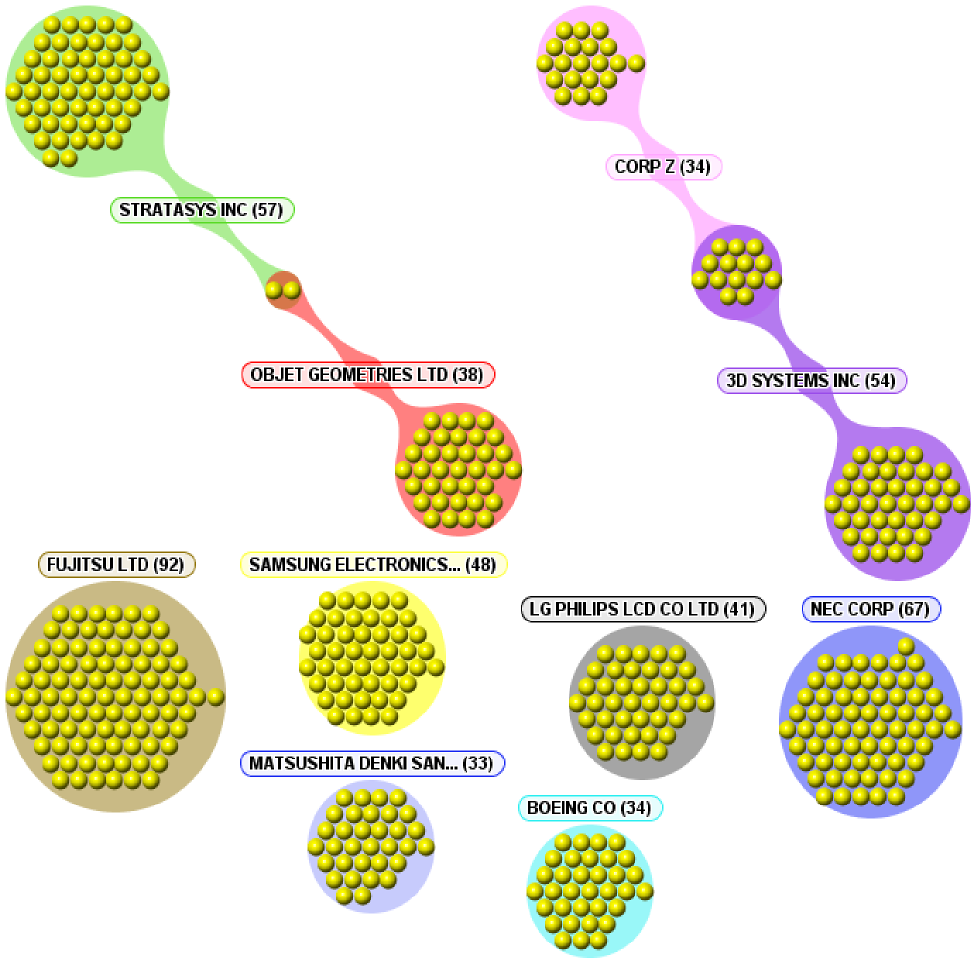

Figure 11: Collaboration map of the top ten applicants

Figure 11 shows that most of the top companies in this dataset have not collaborated with other companies, and are the sole applicants on all of their patents in this field of technology. This may be due in part to the relatively new area of technology such that most companies tend to do their own research in-house. Two companies which are co-named on a number of applications in this dataset are Stratasys and 3D systems.

They are shown as collaborating with companies that they now own. This may have provided an earlier link hint of the mutual compatibility of these companies or represent the transfer of technology between the companies as they adjusted to becoming the same company. The evidence for which theory is true could be given by further examination of the patent data. It may also be an indicator of the widespread use of web based development communities in this field.

2.4 Top inventors

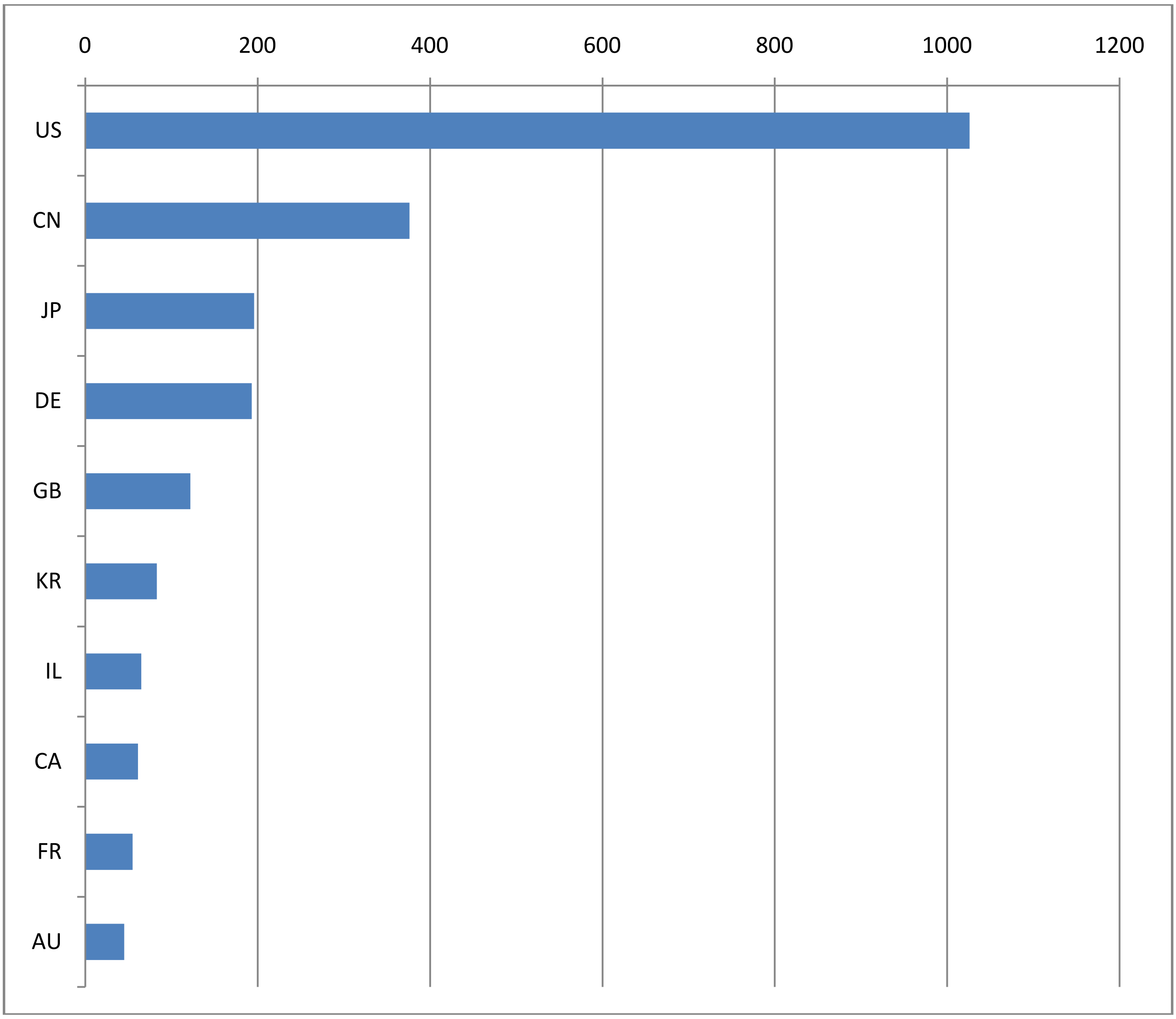

Figure 12: Top inventor countries

There are no UK applicants in the (unadjusted) top 20 applicants but the UK is ranked fifth in terms of location of the inventor. This therefore suggests that the use of inventor country represents a more useful method (compared to priority and publication country) of determining the "source" of an innovation.

The fact that Israel features in the top ten inventor countries shown in Figure 12 can be explained on the basis of patents in the dataset belonging to Objet Ltd, an Israeli based company.. On looking at some of these patents the US is used as a priority country for subsequent filings which go through the PCT (patent cooperation treaty) route. This may be why Israel was not noted on examination of publication country or priority country and adds evidence as to the value in inventor country analysis.

More information regarding individual inventors is given in Section 2.6, where two relatively prolific inventors in the field of 3D printing are examined.

Another way in which the data can be analysed divided out the patent assignees according to applicant type. This can be useful in determining the stage of development of a technology area.

Generally speaking a technology area would be expected to be formed initially with a high degree of academic interest, after which the large corporations would then increase in the patent assignee field at a later stage. However, this more traditional model may be being altered by modern communication systems and awareness of Intellectual Property in general.

Samples of the data from two year, 2000 and 2012 were taken as a contrast in the development stages of the technology. These are illustrated in Figure 13.

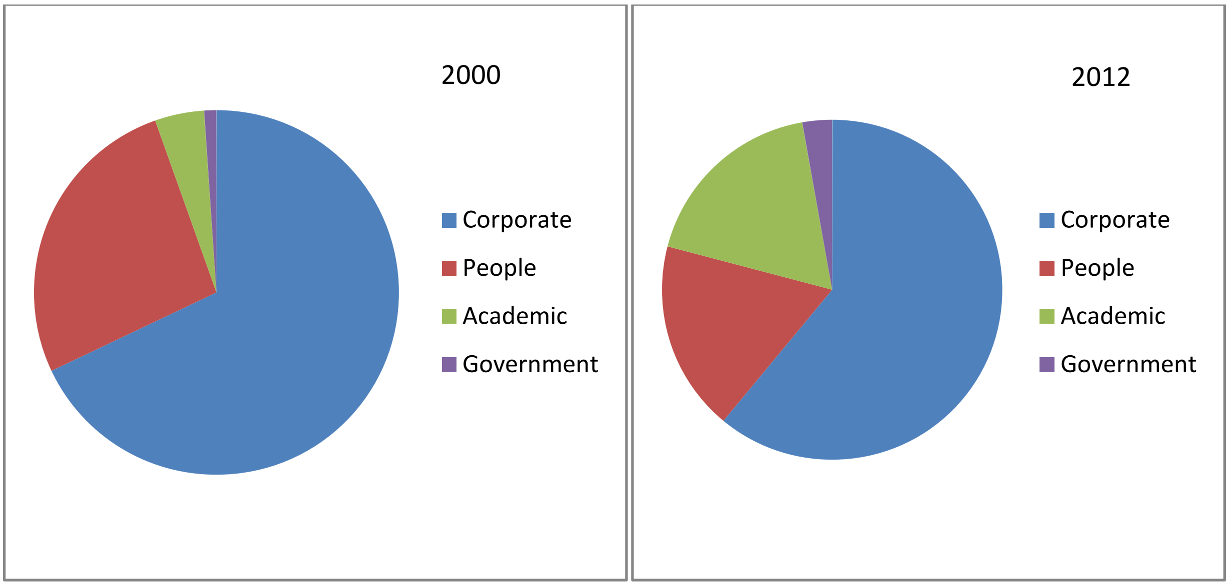

Figure 13: Comparison of applicant type distribution in 2000 and 2012

The current data shows that the proportion of academic interest in this area has actually increased over time as has the interest from individuals at the cost of corporate involvement in gaining patent protection.

This may be due to the fact that academic interest in this technology has increased with further applications being realised as the technology is more widely accepted. For instance, the use of 3D printing to create prosthetics is a sector that probably was not imagined at the outset of this technology but now has become more generally accepted and thus led to increased academic interest in this area. Other models are also suggested by this data in that the Internet may have meant that there has been rapid communication by interested individuals, which has meant that many more individuals have gained an understanding of the technology and experimented with it thus increasing the number of individuals named as patent applicants. There is certainly evidence of many Internet based services that aid with the location and construction of CAD designs which can be used by anyone willing to pay a certain amount, or acknowledge the origin of such files so that 3D printed parts are more available. The cost of buying a 3D printer has also declined massively so that the costs of setting up a business using such technology have declined substantially[39,40].

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[39] The average industrial printer retails for about £47.030 (about $75,000) with some machines costing more than £63,700 (1million dollars). Mc Kinsey Global Institute Disruptive Technologies: Advances that will transform your life, business and the Global Economy, May 2013, Manyika et al

2.5 Technology breakdown

Figure 14 shows the top International Patent Classification (IPC) sub-groups and lists the description of each of these sub-groups. The search strategy outlined in Appendix B used a number of classifications in searching specific areas of the patent classification schemes, so the results shown in Figure 14 in are in line with this.

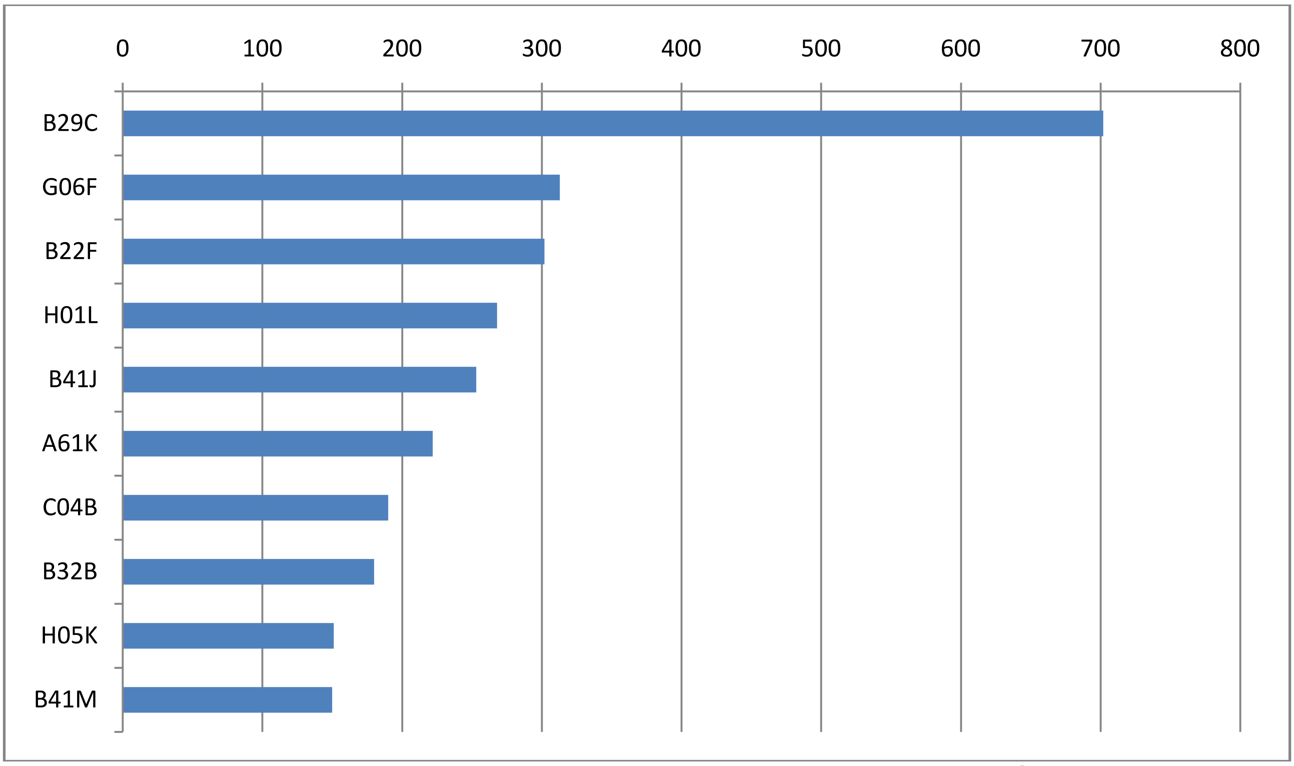

Figure 14: Top IPC areas

The IPC classification marks do not mean much on their own, but when interpreted with the correct key, they provide further information about the technology space. The key to these technology areas is provided in Table 3. The IPC levels have only been provided down to the subclass level. It is also important to note that there is currently a project considering the implication of additive manufacturing and the potential implementation of a classification in this subject matter within the CPC17.The search strategy outlined in Appendix B was relatively focused and was also dependent on searching particular parts of the patent classification schemes, so the results shown in Figure 14 are not unexpected. However other subclasses that have been returned as being of interest were not specifically included in the search and thus serve to highlight the mass interest across different technologies.

[40] 3D printers, substantially for personal use, are now available from the British version of Amazon for under £1000. See the following link: http://www.amazon.co.uk/s/?ie=UTF8&keywords=3d+printer&tag=googhydr-21&index=aps&hvadid=31482296480&hvpos=1s1&hvexid=&hvnetw=g&hvrand=1199566123893589142&hvpone=&hvptwo=&hvqmt=b&hvdev=c&ref=pd_sl_7z5zzp1f2b_b

Table 3: Key to IPC sub-groups referred to in Figure 14

International Classification 8 (IPC 8)	Description
B29C	:Working Of Plastics; Working Of Substances In A Plastic State In General -> Shaping Or Joining Of Plastics; Shaping Of Substances In A Plastic State, In General; After- Treatment Of The Shaped Products, E.G. Repairing
G06F	Computing; Calculating; Counting -> Electric Digital Data Processing
B22F	Casting; Powder Metallurgy -> Working Metallic Powder; Manufacture Of Articles From Metallic Powder; Making Metallic Powder
H01L	Basic Electric Elements -> Semiconductor Devices; Electric Solid State Devices Not Otherwise Provided For
B41J	Printing; Lining Machines; Typewriters; Stamps -> Typewriters; Selective Printing Mechanisms, I.E. Mechanisms Printing Otherwise Than From A Form; Correction Of Typographical Errors
A61K	Medical Or Veterinary Science; Hygiene -> Preparations For Medical, Dental, Or Toilet Purposes
C04B	Cements; Concrete; Artificial Stone; Ceramics; Refractories -> Lime; Magnesia; Slag; Cements; Compositions Thereof, E.G. Mortars, Concrete Or Like Building Materials; Artificial Stone; Ceramics; Refractories; Treatment Of Natural Stone
B32B	Layered Products -> Layered Products, I.E. Products Built-Up Of Strata Of Flat Or Non-Flat, E.G. Cellular Or Honeycomb, Form
H04L	Electric Communication Technique -> Transmission Of Digital Information, E.G. Telegraphic Communication
H05K	Electric Techniques Not Otherwise Provided For -> Printed Circuits; Casings Or Constructional Details Of Electric Apparatus; Manufacture Of Assemblages Of Electrical Components

2.6 Citation analysis

The current dataset can also be examined by the most frequently cited patents in the technology area. This is a known and established[41] method of looking at the most frequently cited patents in a technology space as an indicator of the quality of those patents. During the patent examination process a patent examiner will list all those patents which are considered to be relevant to the wording of the claims in the patent application. Thus, the more frequently a patent is cited can provide an indicator of the value of the disclosure made in the earlier patent, which can thus be related to the quality of the patent. However a very important point in this analysis is to remember that more recent patents will not have had time to gain large number of forward citations and thus this measure will bias the analysis somewhat towards later patents. Therefore the results of the analysis should be used with caution, as they do not provide the “whole picture” when it some to assessing the value or importance of a patent.

The top six patents are shown in Table 4 together with their priority dates and publication dates. The IPC[42] is also listed and it is immediately evident that these patents are classified in many different locations, thus making it challenging for any individuals to locate relevant patents via the classification scheme[43] if they search a single IPC area, or limited text based searching .

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[41] Citation Frequency and the Value of Patented Innovation by Dietmar Harhoff, Francis Narin, Frederic M. Scherer, Katrin Vopel, Discussion Paper FS IV 97-26, Wissenschftszentrum Berlin 1997. Available here: http://www.econstor.eu/bitstream/10419/50945/1/258157852.pdf

[42] The IPC refers to the International Patent Classification system and is a system that is used to organise patents according to their relevant technologies and the content of the application at hand. More information is available here: http://www.wipo.int/classifications/ipc/en/

[43] A Patent Examiner uses a patent classification scheme to search to relevant patents in related areas.

Table 4: Patents with the most forward citations

Patent publication number	Applicant	Number of times cited[44]	Inventors	Publication date	Priority date	IPC	DWPI Abstract title
US5204055	MASSACHUSETTS INST TECHNOLOGY	602	Sachs E ; Haggerty J S; Cima M J; Williams P A; et al	1993-04-20	1989-12-08	B22F 7/04	Three-dimensional printing process to fabricate moulds and prototypes involving selectively applying binder to successively deposited powder layers
US4863538	UNIV TEXAS	572	Deckard C E; Deckard C R	1989-09-05	1986-10-17	B05C 19/00	Appts. for prodn. of parts by selective sintering comprising a laser beam controllably directed onto a layer of powder
US5518680	MASSACHUSETTS INST TECHNOLOGY	353	Cima L G; Cima M	1995-02-07	1993-10-18	A61F 2/00	Complex drug delivery systems and cell regeneration templates provided by computer aided design of solid free-form fabrication processes to form sequential polymeric layers
US5387380	MASSACHUSETTS INST TECHNOLOGY	266	Brancazio D; Bredt J et al	1995-02-07	1989-12-08	B22f7/04	Producing component by selectively bonding powder in deposited layers by applying bonding liquid employing 3-dimensional printing technique, based on ink jet printing and building up successive layers
US6259962	OBJET GEOMETRIES LTD	205	Gothait H	2001-07-10	1993-03-01	B29C 41/36	Three dimensional printing system for computer aided design models, cures 3D models build up in layers by dispersing photopolymer material, using UV or IR radiation optionally
US 944817	UNIV TEXAS	205	Barlow J W; Beaman J Jet al	1990-07-31	1986-10-17	B05C 19/00	Formation of multilayer parts by sintering comprises depositing layers of powder mixt. materials and scanning each individual layer with a sintering radiation beam

[44] The values used for the number of times that a patent has been cited are taken from the number of time that that patent family has been cited rather than the individual patent, as most people will not search for a single, particular member of patent family as the disclosure of a single member of the same family will be sufficient for someone to make a decision on the relevance of that disclosure In some cases the English language version of a patent family member may be sought which can affect the number of times that an individual family member is cited.

Many of these patents have older priority dates so that they will be coming to the end of their patent term. Much of this has been made in the press[45], with the hope that the ending of the patent terms will “open up” the technology space for further development as the expiry of patents has to the Rep Rap project.[13] Indeed one set of patents which is shortly due to expire is that from the University of Texas, filed by Deckard et al relating to Selective Laser Sintering (SLS). One of these patents is listed as the third most cited patent in the current dataset. Figure 15 is an example of a “citation tree” for a patent that has been cited many times, so it is not necessarily meant to be legible.

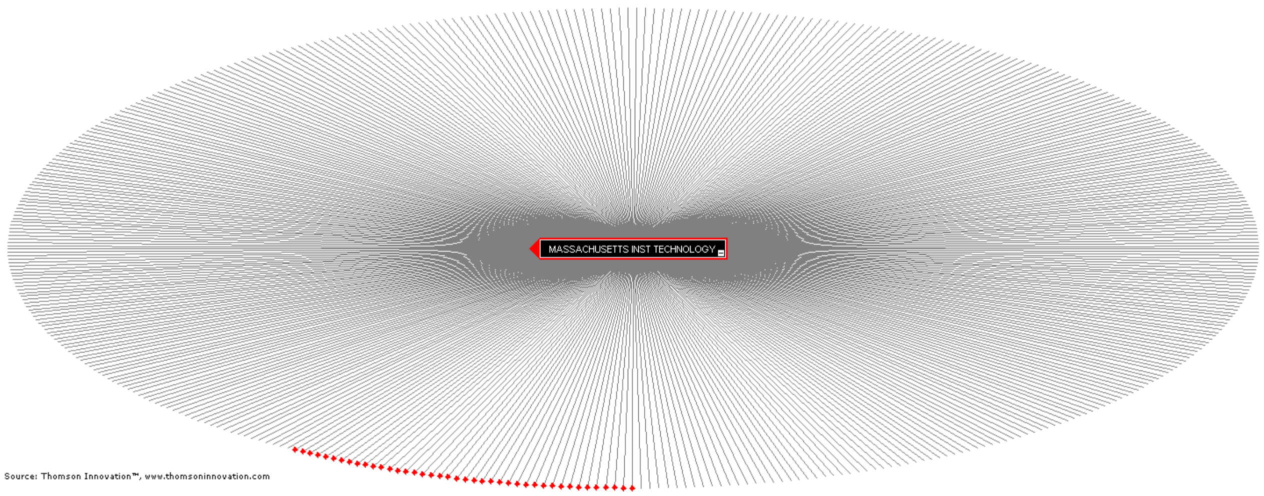

Figure 15: Forward citation tree (one generation) for US5204055 with those forward citations where Massachusetts Institute of Technology (MIT) is named as a patent assignee highlighted. Each line represents a patent listing the current patent as a relevant document

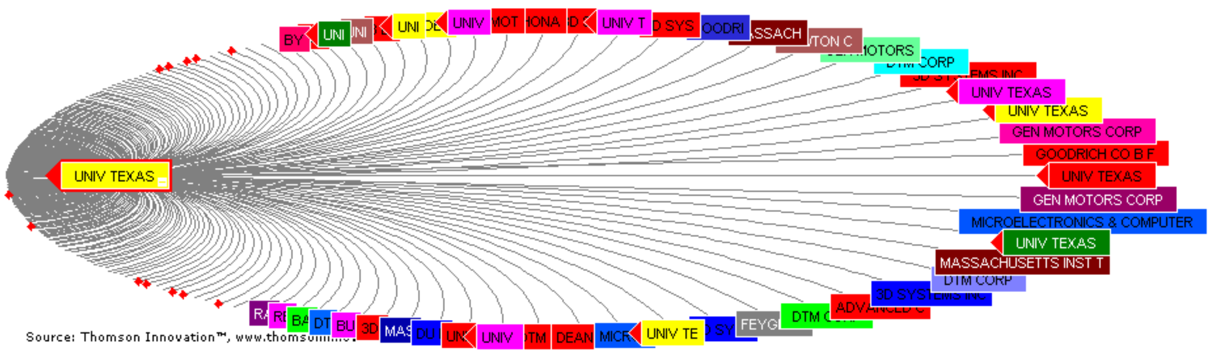

Figure 16: Forward citation tree (one generation) for US4863538 with those forward citations where University of Texas is named as a patent assignee highlighted, and the listed patents are coloured according to the IPC

45 Disruptive Technologies: Advances that will transform life, business, and the global Economy, Manyika et al, Mc Kinsey Global Institute, May 2013, pp108, available from: http://www.mckinsey.com/insights/business_technology/disruptive_technologies

Figure 17: Forward citation tree (one generation) for US5518680 with those forward citations where the listed patents are coloured according to the IPC

Figure 15 to Figure 17 show citation trees for the three patents in the dataset with the most forward citations (US5204055, US4863538 and US5518680). As noted in the earlier footnote, generally speaking, forward citations (number of times a patent application is subsequently cited) are considered to give a more useful indication of patent quality than backward citations (earlier publications cited by the patent examiner against the novelty or obviousness of the patent application being examined) so the citation trees are limited to forward citation analysis.

It is important to realise that the patents that are listed as citing the three patents highlighted in Figure 15 to Figure 17 may not be directly related to 3D printing, and as is shown in these figures, these patents are relevant to many different sections of the IPC. It is also evident that these patents have been cited so many times that it is difficult to determine who the applicants are and what their interests in the content of the disclosure(s) are.

Figures 11 and 12 both show the patents which are cited by the same applicants highlighted. This is to address the issue of self-citing. This process is prevalent in US patent applications where the patent applicant is required to provide a list to relevant prior art (i.e. relevant documents) at the time of filing. Many applicants list their own patents as they believe that these are the most relevant applications to the patent at hand, and thus these documents, may make up a greater proportion of the citations. This does not appear to be the case, in the current instance as the self-cited documents only make up a small proportion of the listed cited documents.

It should be noted that citation trees can be useful in understanding the patent citing process in general, but their use can be limited because of poor coverage of cited/citing data for some jurisdictions. US citation data is very good but, consideration of the patents listed in Table 4, should be understood that any conclusions drawn from this data (in part due to the good US citation coverage) regarding the most essential or highest quality patents, should be taken with caution.

Referring back to the patents which are shortly due to expire, assigned to Carl Deckard and Joe Beaman; a plot has been drawn showing the activity of these two inventors over time from this dataset in Figure 18. Dr Beaman still works at the University of Texas as a professor, while Dr Deckard works for Structured Polymers, developing material for SLS and other powder bed fusion Additive Manufacturing processes.

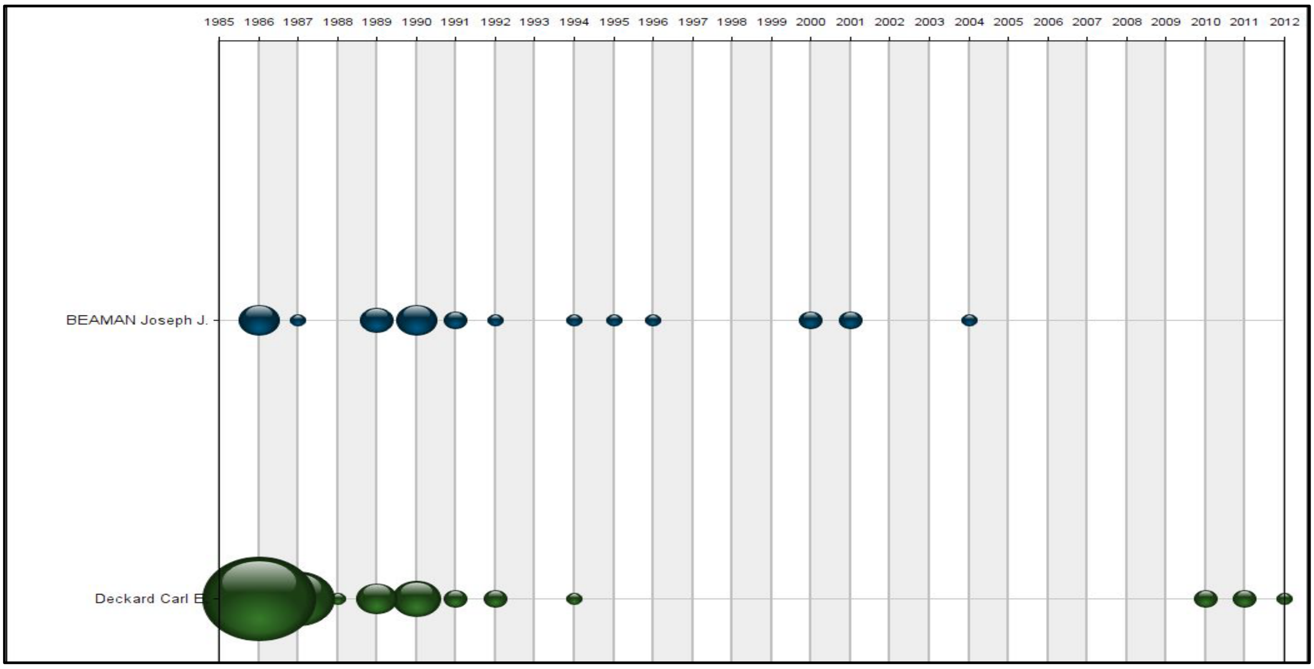

Figure 18: Plot of inventor activity for two inventors, J Beaman and C Deckard

The background concerning these two inventors makes sense of the plot shown in Figure 18, as it demonstrates that Dr Deckard was initially very involved with the area of Selective Laser Sintering and that subsequently he left the world of academia, which involved research that was subsequently patented. Working elsewhere he was not named on many patent applications, but on changing job he became involved in patent applications once more. It is interesting to note that both Dr Deckard and Dr Beaman were involved in a company, DRM, to exploit the methodologies and technologies set out in these patents. This company was subsequently acquired by 3D Systems[46]. More recently, in his current job, he appears to be named in a number of patent applications.

[46] This company was acquired by 3D Systems in 2001

2.7 Patent landscape analysis

Much is made in the media of "technology space". Using a data visualisation technique allows a visualisation of a "technology space" through the representation of the data. Published patents (not patent families) are located on a patent "map" or "landscape" by dots so that and the more intense the concentration of patents (i.e. the more closely related they are) the higher the topography as shown by contour lines. Where there are large numbers of similar patents then there are "snow capped peaks", when there are low numbers of similar patents there are "deep waters". The patents are grouped according to the occurrence of keywords in the title and abstract and examples of representative keywords appear on the surface of the patent map[47].

The full dataset of about 30,000 published patent documents (note the results of the search in Appendix B, which differs in final dataset scope from that used in the earlier analysis) were used to produce the patent landscape shown in Figure 19. The largest 'snow-capped peak' in the top left of the map shows that the highest concentration of patents in this dataset relates to patents comprising keywords such as "Acid" and "mixed ester", which suggests that the area relating to material for 3D printing contains the most patent applications within this technology space.

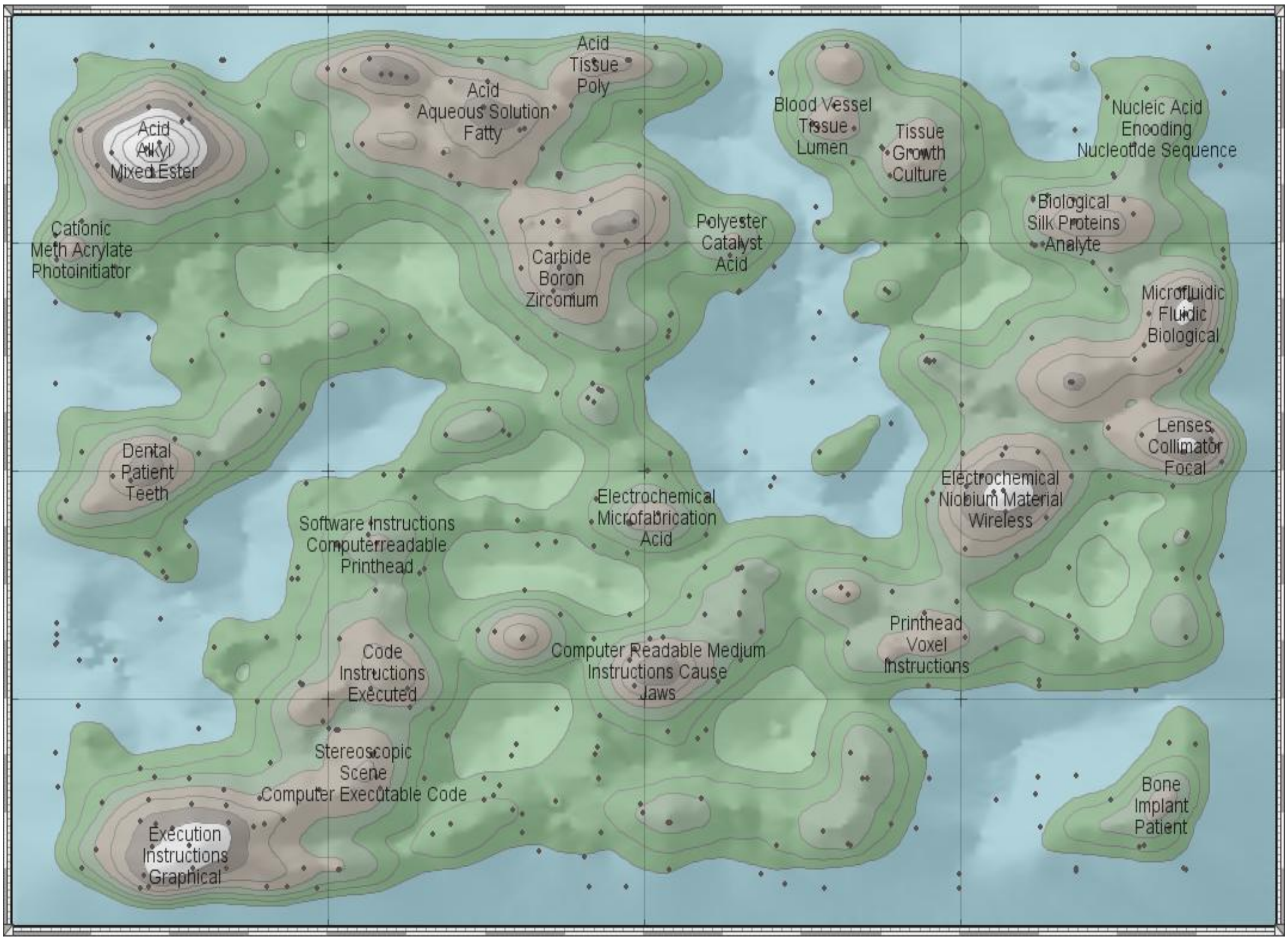

Figure 19: 3D printing patent landscape map

47 Further information about how patent landscape maps are produced is given in Appendix D

However, this diagram alone does not really aid the reader in comprehending what the technology space entails. Figure 20 shows areas of the landscape map overlaid with circles representing where particular technologies are represented in the figure. It is important to understand that the map itself is composed of the patents from the dataset (about 30,000) and thus cannot show all of the individual patent records on a single map. It is also essential to understanding that the map itself is an interrogative tool in that when accessed as a data the user can interact with the map i.e. search for particular patents or assignees or indeed, technologies. This is difficult to represent in the current report. More information about how such maps are obtained is given in Appendix D.

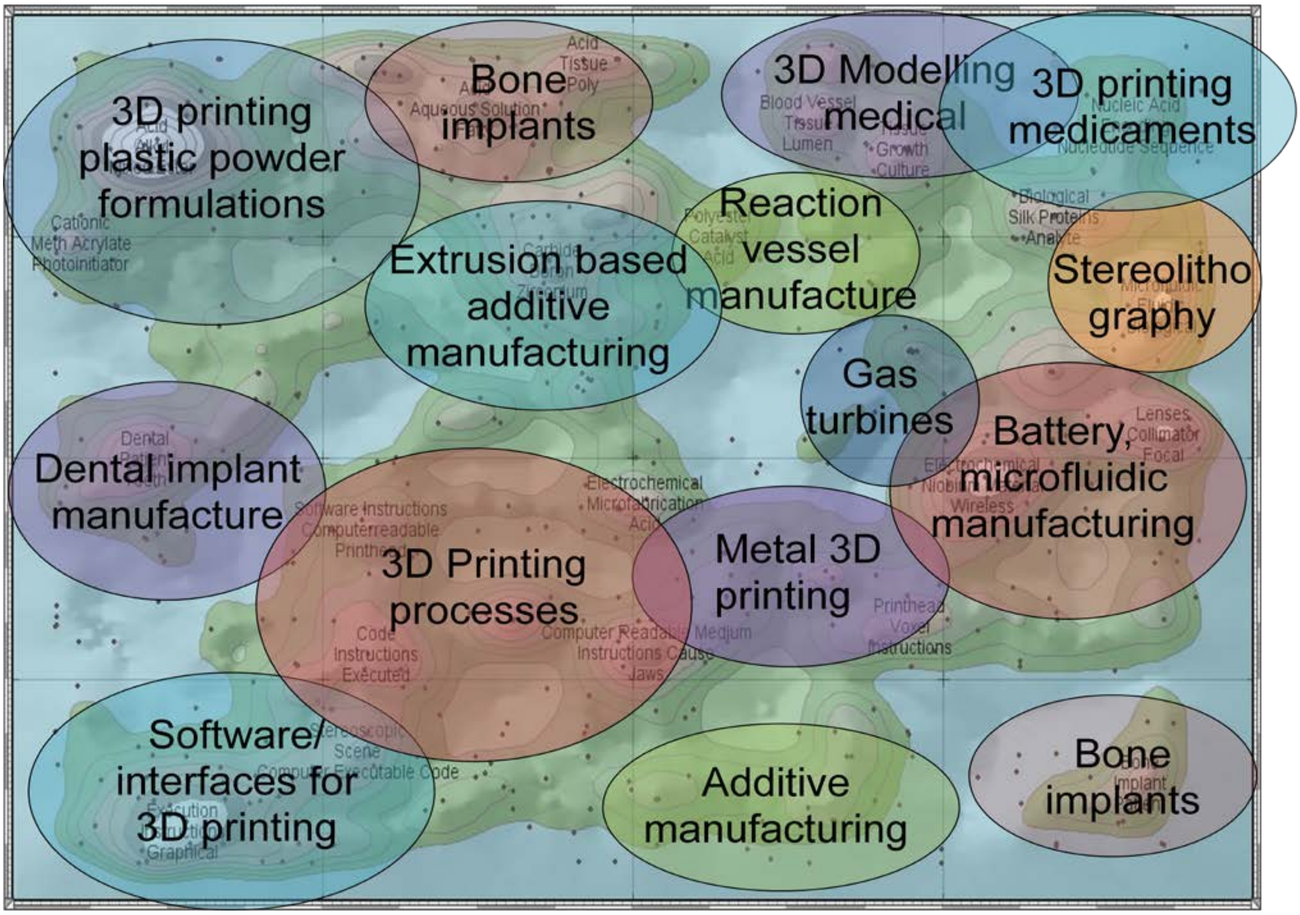

Figure 20: 3D printing patent landscape map with areas of interest highlighted

An interesting fact from the maps shown in Figure 19 and Figure 20 is that there is a high degree of interest in biotechnological aspects of this field. The area of 3D printing is well known as being an example where dental implants and prosthetics can be custom made for the user without creating high degrees of waste or causing difficulties in manufacture such as excess time.

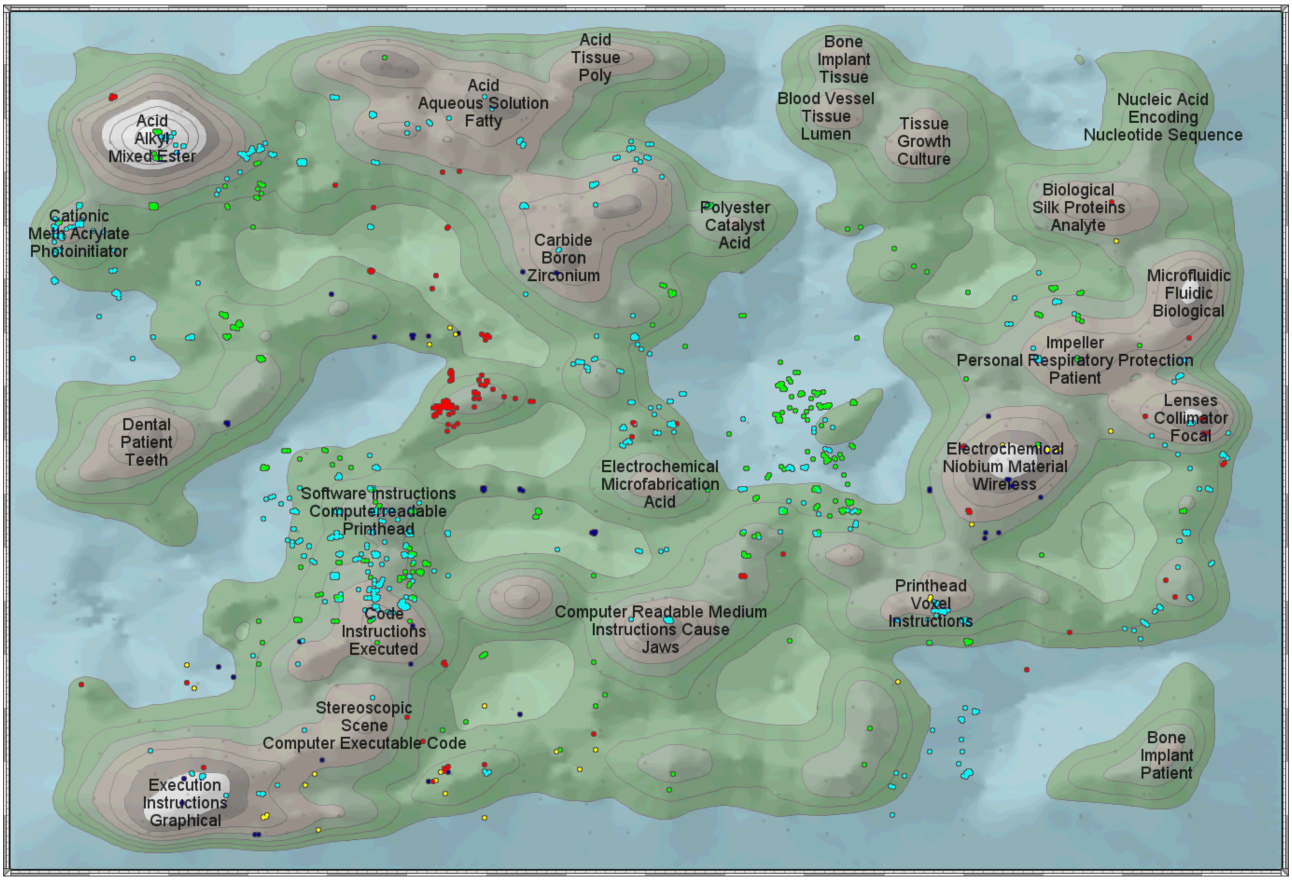

Figure 21: 3D printing patent landscape map with the top five applicants highlighted

✓	Pub	Name	Type
		Topic Index	
●		Samsung	
●		Stratsys	
●	Pub	NEC	
●	Pub	3d Systems	
●	Pub	Fujitsu	

Figure 22: Key to Figure 21 stating which colours are relevant to which company

The landscape map in Figure 21 shows the top five applicants in this filed and can be related to their key areas of technology on the patent map shown in Figure 20. It is important to remember that the underlying data from which this map (Figure 22) is plotted is different to that used to generate the earlier figures (i.e. Figure 3).

2.8 Non-patent literature analysis

A search of non-patent literature (NPL) was performed as set out in Appendix D.

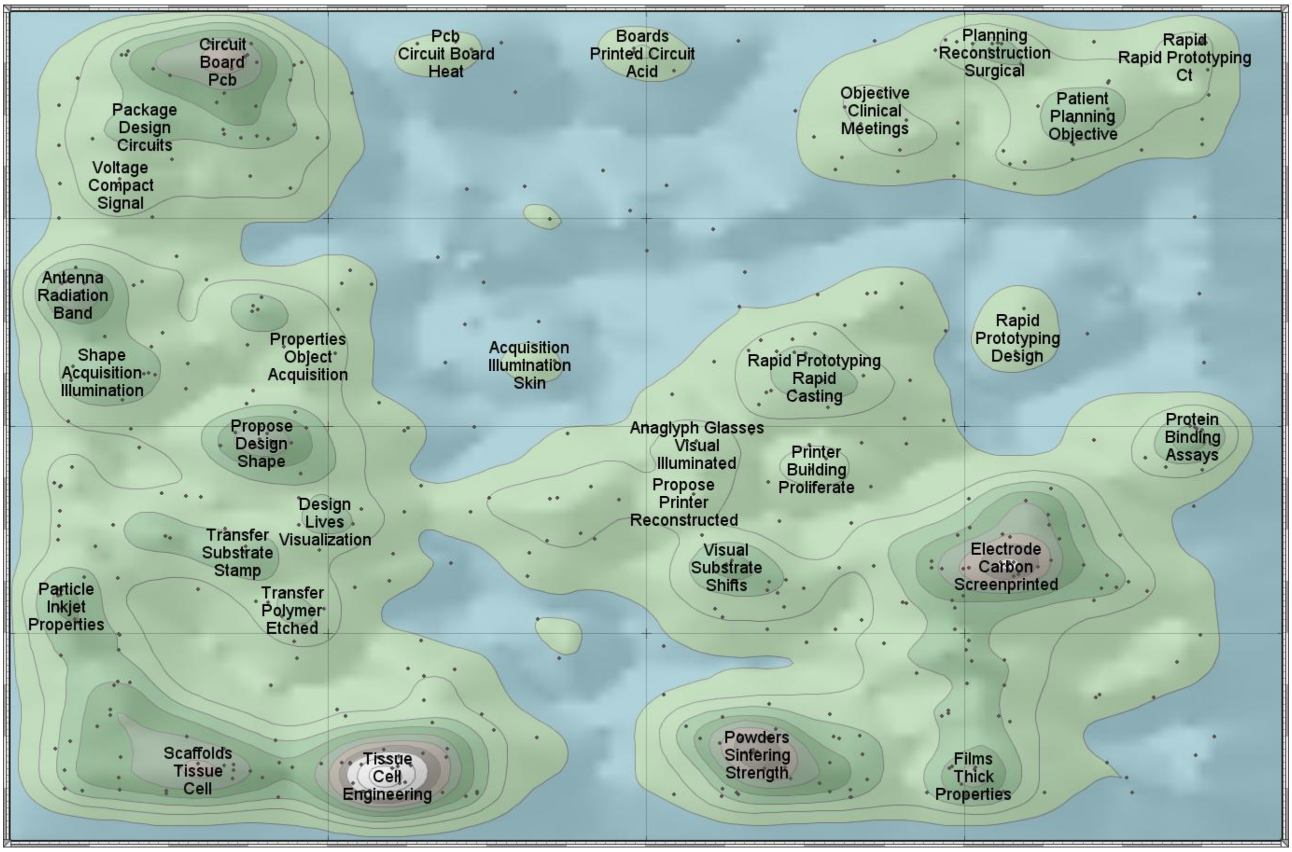

Figure 23: Landscape map of 3D printing NPL

Figure 23 represents a landscape based on the content of a number of journal/conference proceedings/articles relating to 3D printing, published by Thomson from their Web of Science database. It represents 1066 individual records and highlights some of the key areas of interest in Academia.

The landscape map may also be divided up into areas of particular interest as is shown in Figure 24.

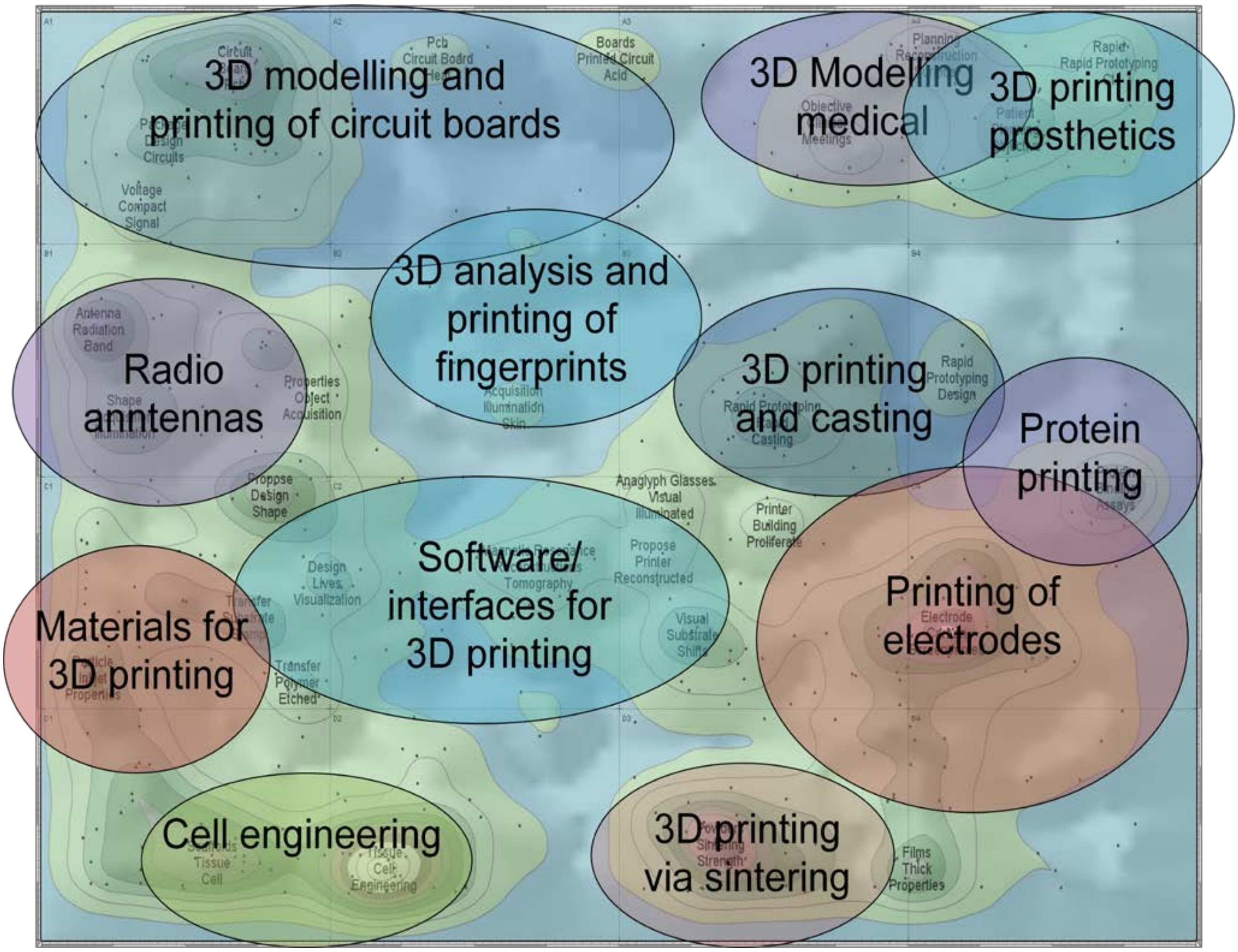

Figure 24: Landscape map of 3D printing NPL with areas of technology highlighted

The contents of Figure 23 and Figure 20 are not directly comparable as the search of NPL was date restricted from 2008 to 2013 and used a different search strategy (see Appendix B and Appendix E). However, looking at the landscape map relating to NPL still demonstrates a key interest in biotechnology, as the “snow capped peak” in the left hand part of Figure 23 is related to this subject area. In looking at these two representations of different forms of data similar subdivisions of technology have been brought out, thus showing that there may be some relationship between NPL and patent filings. This finding is not unexpected.

An analysis of publication year has been performed for documents in the Landscape map. The results of which are shown in Figure 25 and Figure 26.

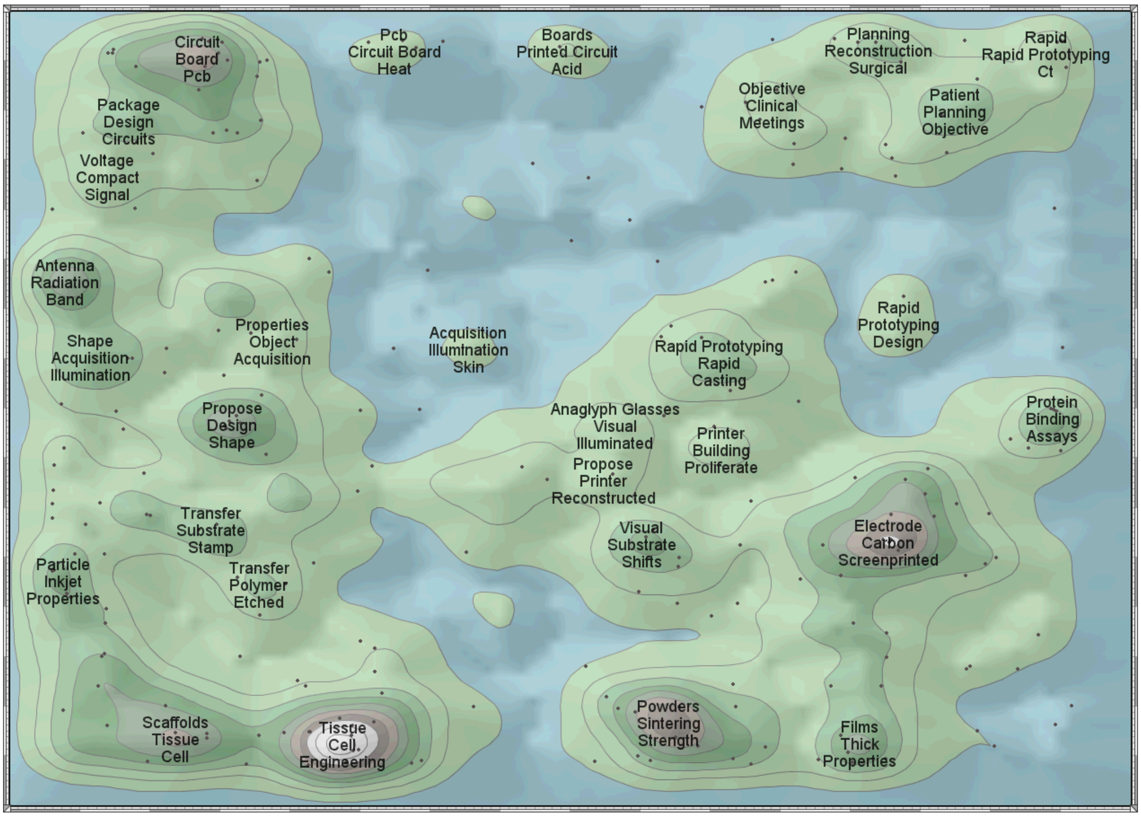

Figure 25: Landscape map of 3D printing NPL with articles highlighted published in 2008-2010 (464)

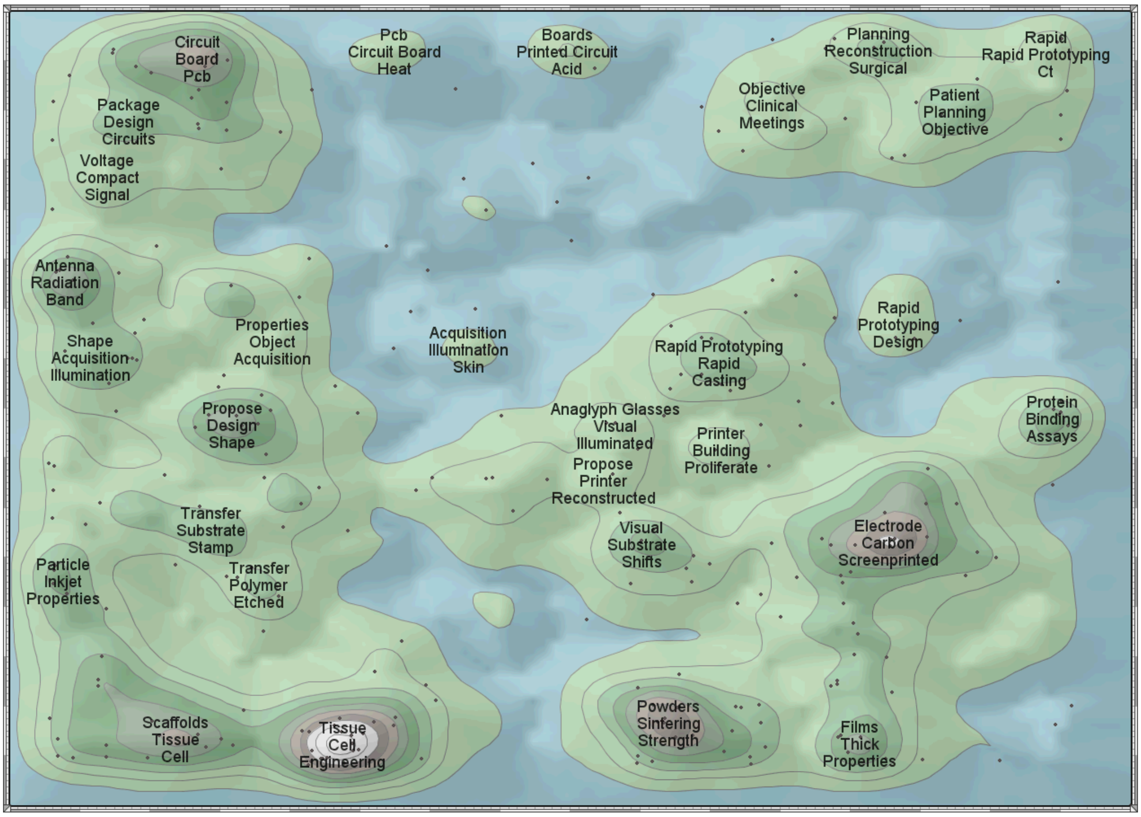

Figure 26: Landscape map of 3D printing NPL with articles highlighted published in 2010-2012 (560)

No immediate trends are visible from either map presented in Figure 25 or Figure 26 other than to comment that the number of NPL documents is increasing over time. This is not the full story as Figure 27 demonstrates.

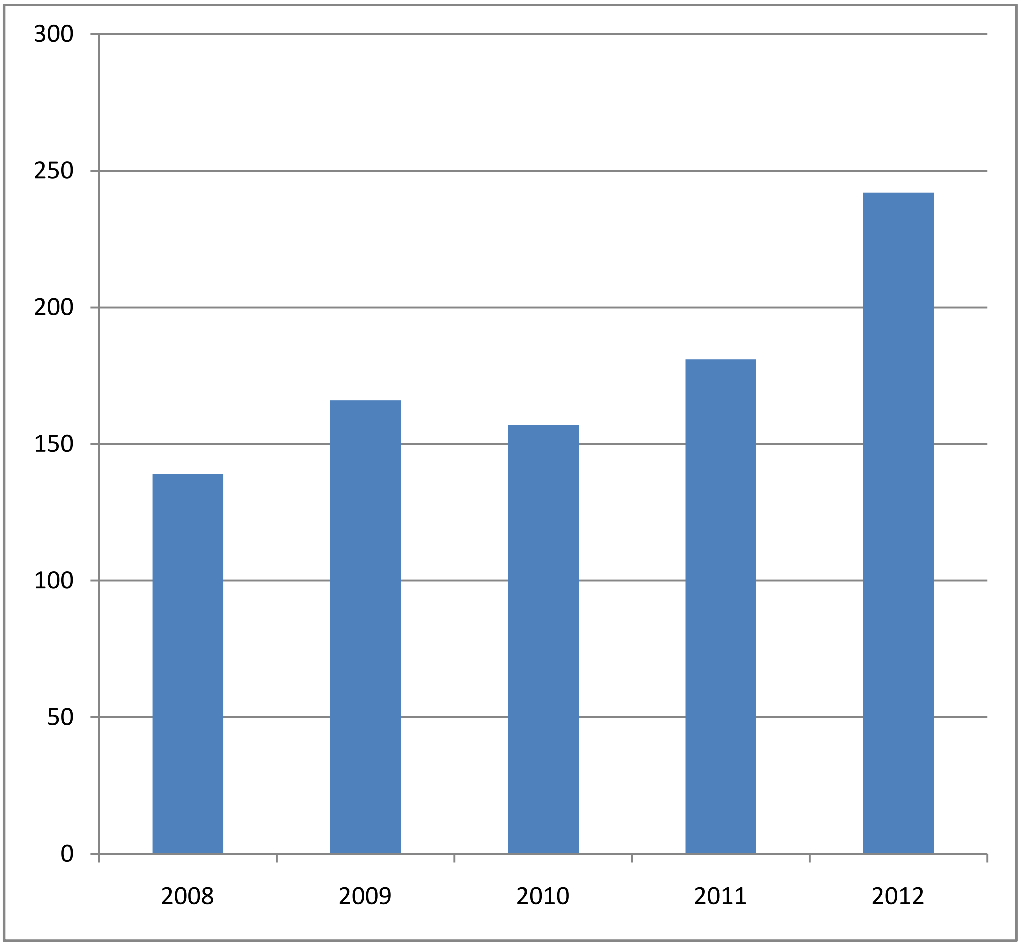

Figure 27: Plot of the volumes of 3D printing NPL published in the UK

Looking at this figure, it shows that the number of published applications in 2012 is upon the number published in 2011; however, given the fluctuation in the number of publications in this field it is difficult to draw any substantive conclusions.

As illustrated by Figure 27 there were 240 docs published in 2012 alone. Of these, the top five assignees are listed in Table 5.

Table 5: Table Showing the top five NPL assignees for 2012

No of documents published	Organisation
7	Harvard University
6	Massachusetts University of Technology
6	University of California System
6	Georgia Institute of Technology
5	Shandong Tumour Hospital

This shows that Harvard University some out as the top assignee in this area being named on seven publications in 2012. However, given the relatively low volumes of documents assigned to any individual organisation; this suggests that research is occurring in many places and is not yet centred in a single group of ”main players”.

Table 6: Details of some of the NPL publications made by Harvard University in 2012

Organisation	Publication	Author
Harvard University,	Fabricating Articulated Characters from Skinned Meshes	Bacher, M
University of Pennsylvania; Harvard University; Massachusetts Institute of Technology; Howard Hughes Med Inst;	Rapid casting of patterned vascular networks for perfusable engineered three-dimensional tissues	Miller, JS
Harvard University,	Design and Fabrication of Soft Artificial Skin Using Embedded Microchannels and Liquid Conductors	Park, YL
Harvard University,	Microfabrication of complex porous tissue engineering scaffolds using 3D projection stereolithography	Gauvin, R
Harvard University, Rensselaer Polytech Inst	The integration of 3-D cell printing and mesoscopic fluorescence molecular tomography of vascular constructs within thick hydrogel scaffolds	Zhao, LL

These landscape maps can also be examined via subject area as is highlighted below:

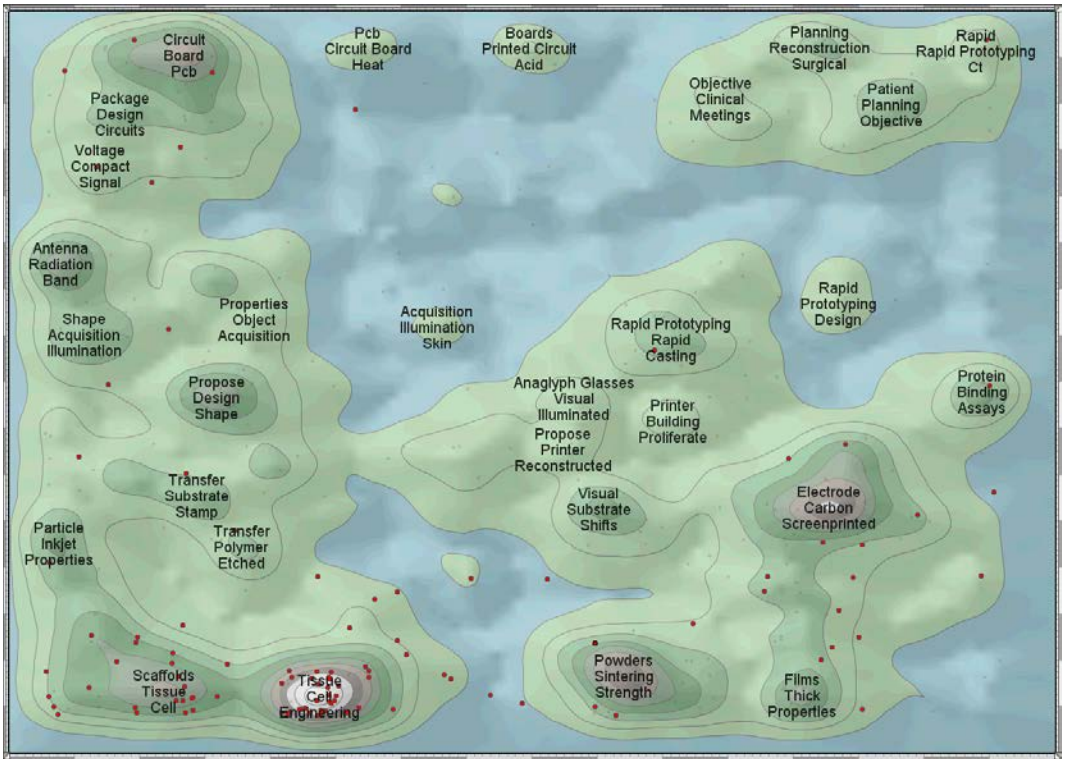

Figure 28: Landscape map of 3D printing NPL showing documents with the term tissue highlighted

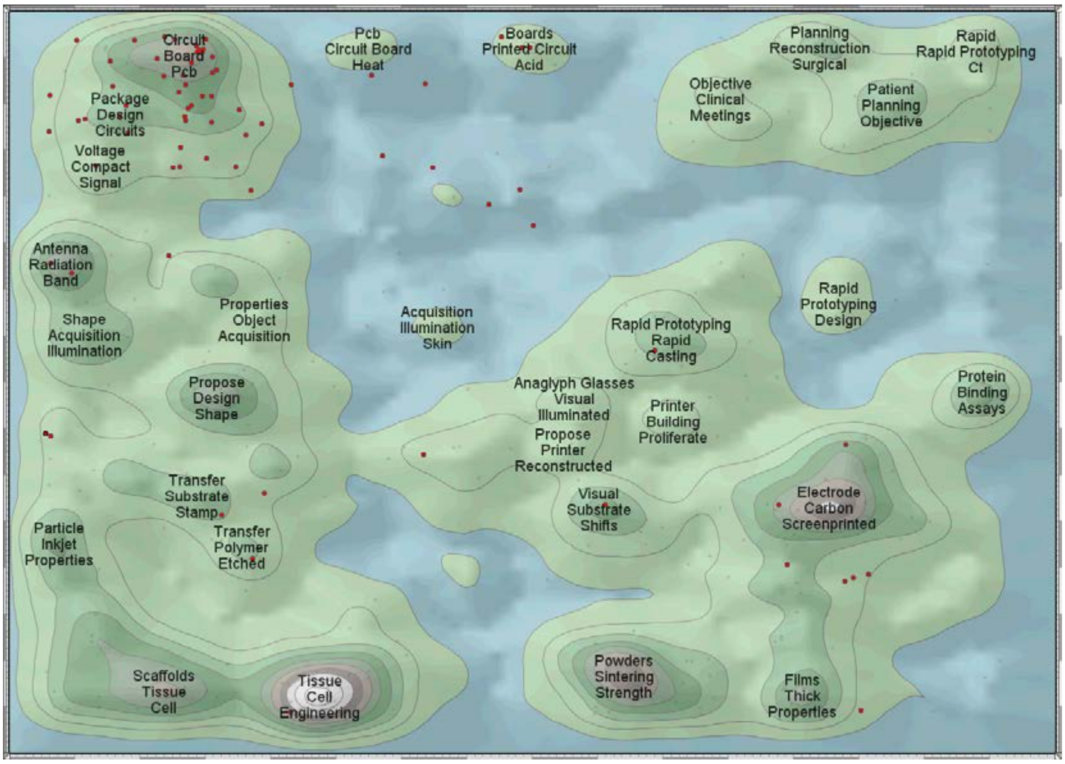

Figure 29: Landscape map of 3D printing NPL showing documents with the term printed circuit highlighted

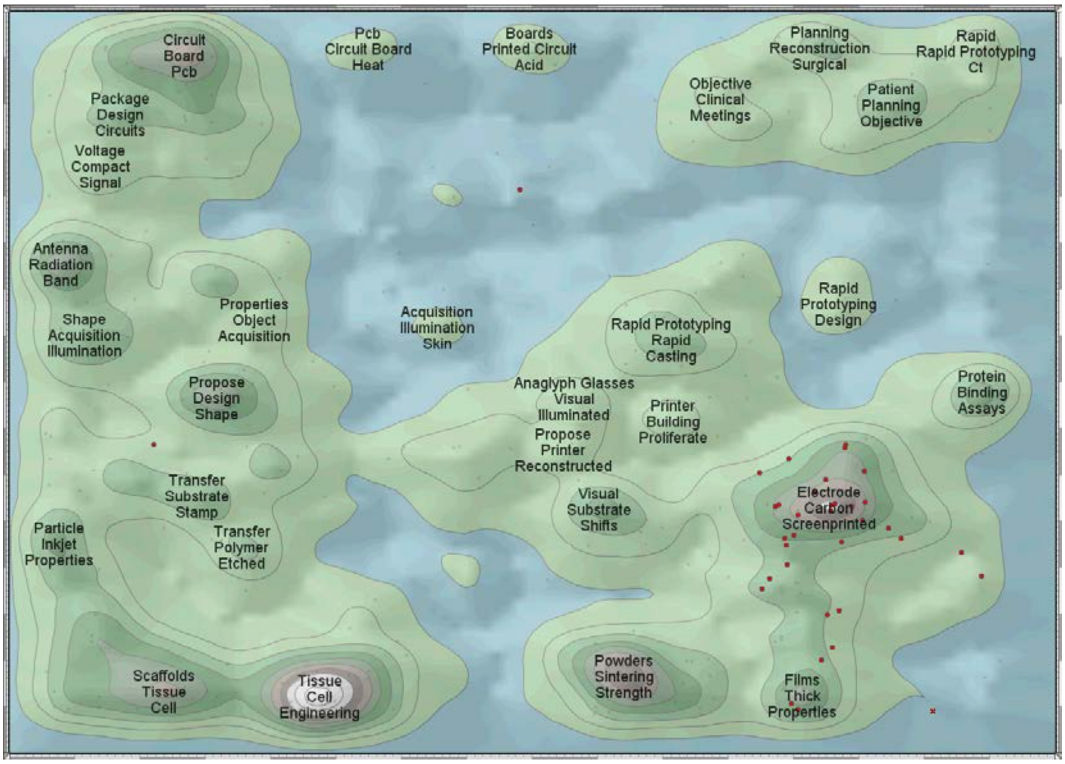

Figure 30: Landscape map of 3D printing NPL showing documents with the term electrode highlighted

These correspond well with Figure 24, where the areas of key terms are used to subdivide the map. However, for some further detail, some examples of the documents listed in these key areas of the map are given in Table 7.

Table 7: Table of some documents listed on the NPL map shown in the earlier figures

Key term	Title	Publication year	Author
Tissue	Cell, scaffold and growth factor patterning via 3D printing	2012	Sawkins et al
Printed circuit	Contact Printed Micromechanical Systems	2010	Packard C et al
Electrode	A 3D Printed dry electrode for ECG/EEG recording	2012	Salvo P et al

Conclusions

The area of 3D printing has increased massively since 1980 (which constituted the date limitations of the current dataset). However, the fact that there is patent data from this era which is still relevant to this field of technology is illustrative of the fact that this technology has existed in many forms for some time, and that it is only recently with advances in computing and software combined with large amounts of media interest, (plus the expiration of a number of useful patents) that has led to the current status regarding this technology.

One dataset gives about 30,000 published patent applications since 1980 relating to 3D printing which cuts across many areas technology. Patenting activity in the area of 3D printing does not appear to have been affected by recent global economic crisis. The US appears to lead the way in this technology space with most applicants seeking patent protection there.

A number of patents have been highlighted as being cited in patents perhaps providing an indication of the quality of the disclosures contained therein. Looking at other sources of data either through non patent literature (NPL) and Internet search information has confirmed that there has been an increase in interest in this area through an expansion of the numbers of academic papers, and increasing use of Internet search terms, which can be related to 3D printing. Including these sources of data allows a fuller picture of this developing technology to be achieved.

Key conclusions for examining this data show that there has been a large increase in both the media interest and volumes of patent filings in this area of technology. The technology itself is not new (note the patents from 1980), but the tools which allow the underlying technologies to be exploited have undergone substantial improvement over this time frame. Filings from the year 2000 onwards have demonstrated the largest increase in volume, despite the potential effects of the economic downturn in this time period.

The UK does not appear to have a degree of specialisation in this area from the current patent filings. In looking at the patent data, Australia has been listed as a country with a high degree of specialisation, which can be linked back to the activity of a prolific inventor, Kia Silverbrook. The UK does perform well in terms of the location of the inventor rather than as a location for filing of the application or the country from which priority is taken.

Most of the top applicants are US based companies. However, many of the inventors are not US based, but file their patents in this location .Of the top applicants, most of those listed do not collaborate with others. It is also evident from the data that the top applicant holds many patents in the area, but that these are older than those from other top applicants and will expire soon.

There are a number of highly cited patents in this technology with some of them listed in the text. These patents are now relatively new and will expire soon. It will be interesting to see how the technology area evolves given this expiry. There is also increasing academic share of applications over the time period 2000-2012

A review of landscape maps of this technology reveals that key areas of interest include biomedical applications, circuits and electrode fabrication.

Future work could take many forms given the diversity of the technologies contained within the dataset. It would to interesting to look at Trade Mark filings in this area to see if there is a relationship between this data and NPL and patent data. Further investigation of patent filings could reveal changes in the manner in which technology is applied and used as well as potentially contributions to changes in business development models.

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Appendix A Interpretation notes

A.1 Patent databases used

The *Thomson Reuters* World Patent Index (WPI) and the European Patent Office (EPO) EPODOC databases were interrogated, both of which hold bibliographic and abstract data of published patents and patent applications derived from the majority of leading industrialised countries and patent organisations, *e.g.* the World Intellectual Property Organisation (WIPO), European Patent Office (EPO) and the African Regional Industry Property Organisation (ARIPO). It should be noted that patents are generally classified and published 18 months after the priority date. This should be borne in mind when considering recent patent trends (within the last 18 months).

The WPI database contains one record for each patent family. A patent family is defined as all documents directly or indirectly linked via a priority document. This provides an indication of the number of inventions an applicant may hold, as opposed to how many individual patent applications they might have filed in different countries for the same invention.

A.2 Priority date, application date and publication date

There are generally three dates which can be associated with a patent application as follows:

Application date: The date on which a physical application was made for a patent. This enables an accurate temporal reflection of the technical content of a patent application.

Priority date: A patent can claim priority from an earlier application. This usually happens for two reasons: a) when an application is filed in one country, international convention dictates that the applicant then has 12 months to file a corresponding application abroad. Thus the patent application would then have a priority date, which indicates the earliest date attributed to the invention; b) an earlier application may contain part of a subsequent invention so a subsequent application, made within 12 months of filing, may claim priority from the earlier application. However, in the new application, this date is only valid for that part of the invention which appears in the earlier application. Care should therefore be taken when analysing the priority date of an invention.

Publication date: The date when the patent application was published. A patent is normally first published (‘A’ publication) 18 months after the priority date or the application date, whichever is earlier. Depending on the jurisdiction, a patent is then given a ‘B’ or ‘C’ publication code when it is granted. Any further publications (*e.g.* following correction) are given a numbered publication code in a most jurisdictions (*e.g.* ‘A1’, ‘A2’, ‘B1’, ‘B2’ *etc*).

The analysis presented in this report is primarily based on priority year to give the earliest indication of innovative activity.

A.3 WO and EP patent applications

International patent applications (WO) and European patent applications (EP) may be made through the World Intellectual Property Organization (WIPO) and the European Patent Office (EPO) respectively.

International patent applications may designate any signatory states or regions to the Patent Cooperation Treaty (PCT) and will have the same effect as national or regional patent applications in each designated state or region, leading to a granted patent in each state or region.

European patent applications are regional patent applications which may designate any signatory state to the European Patent Convention (EPC), and lead to granted patents having the same effect as a bundle of national patents for the designated states.

Figures for patent families with WO and EP as priority country have been included for completeness although no single attributable country is immediately apparent.

A.4 Patent documents analysed

Appendix B provides full details of the search strategy used to extract the dataset used for analysis. The applicant and inventor data was cleaned to remove duplicate entries arising from spelling errors, initialisation, international variation (Ltd, Pty, GmbH *etc*.), or equivalence (Ltd., Limited, *etc*.).

No time limits were applied to the initial dataset although the more recent patents in the dataset are those that may still be in force. However, the current status of patents has not been checked and the claims of individual patents were not considered. Therefore, even though some competitors and customers have not been recently active, there exists a risk of granted patents of relevance still being in force.

A.5 Analytics software used

The main computer software used for this report is a text mining and analytics package called *VantagePoint*[48] produced by *Search Technology* in the USA. The patent records exported from the EPODOC and WPI patent databases are imported into *VantagePoint* where the data is cleaned and analysed. In addition, the patent landscape maps and citation trees used in this report are produced using *Thomson Innovation*[49], a web-based patent analytics tool produced by *Thomson Reuters*.

[48] http://www.thevantagepoint.com
[49] http://info.thomsoninnovation.com

Appendix B Search strategy

The patent dataset was identified in conjunction with patent examiner technology-specific expertise. A search strategy was developed (see below) and the resulting dataset was extracted in August-October 2013 using International Patent Classification (IPC) codes, Co-operative Patent Classification (CPC) codes and keyword searching of titles and abstracts in the European Patent Office (EPO) EPODOC databases and full text searches in *Thomson Reuters* World Patent Index (WPI). Further refinement of the initial dataset was performed through a visual analysis of the patent family titles to ensure that the dataset was relevant. This refinement took place in *Vantage Point* so that the datasets used from *Thomson Innovation* are of wider scope than those produced via *Vantage Point*. This is reflected in the landscape maps produced.

The searches used were:

Search 1:

ALL=((additive NEAR manufactur*) OR ((Additive NEAR laser) NEAR manufactur*) OR (additive NEAR fabric*) OR ((Additive NEAR laser) NEAR Fabric*));

4542 patent records found out of 79,396,995 searched

Search 2:

ALL=(((3 NEAR D) or 3d or (three NEAR dimension*)) NEAR (Print* OR Fabricat*OR ADJ manufactur*));

10,446 records found out of 79,396,995 searched (Display Limit 60,000)

Search 3:

ALL=(((free-form OR (Free NEAR form)) NEAR (Manufactur* or fabrica*)) OR EBF3 OR (Rapid NEAR (Prototyp* OR Manufact*)));

24,822 records found out of 79,396,995 searched (Display Limit 60,000)

Search 4:

ALL=(((Select* NEAR (sinter* OR Laser* OR HEAT*)) NEAR3 (Deposit* OR Sinter*)) OR SHS OR SLS);

36,344 records found out of 79,396,995 searched (Display Limit 60,000)

Search 5:

ALL=(((laminat* NEAR object*) NEAR (Manufact* OR fabricat*)) OR ((Fus* NEAR Deposit*) NEAR Model*) OR (generativ* NEAR Print*));

3,574 records found out of 79,396,995 searched (Display Limit 60,000)

The results of these searches exceeded 60,000 documents which were then exported into Vantage Point® Analyser and combined there into families and a single data file. The “cleaning” process, as referred to earlier, was also performed at this point.

Appendix C Relative Specialisation Index

Relative Specialisation Index (RSI) was calculated as a correction to absolute numbers of patent families in order to account for the fact that some countries file more patent applications than others in all fields of technology. In particular, US and Japanese inventors are prolific patentees. RSI compares the fraction of 3 d printers found in each country to the fraction of patents found in that country overall. A logarithm is applied to scale the fractions more suitably. The formula is given below:

$$\log_{10}\left(\frac{n_i/n_{total}}{N_i/N_{total}}\right)$$

where
n_i = number of 3D printers in country i
n_{total} = total number of 3D printers patents in dataset
N_i = total number of patents in country i
N_{total} = total number of patents in dataset

The effect of this is to highlight countries (in this study, Mexico and Brazil in particular, as shown in Figure 7) which have a greater level of patenting in 3D printing than expected from their overall level of patenting, and would otherwise appear further down in the lists.

Appendix D Patent landscape maps

A patent landscape map is a visual representation of a dataset and is generated by applying a complex algorithm with four stages:

i) **Harvesting documents** – When the software harvests the documents it reads the text from each document (ranging from titles through to the full text). Non-relevant words, known as stopwords, (*e.g.* “a”, “an”, “able”, “about” *etc*) are then discounted and words with common stems are then associated together (*e.g.* “measure”, “measures”, “measuring”, “measurement” *etc*).

ii) **Analysing documents** – Words are then analysed to see how many times they appear in each document in comparison with the words’ frequency in the overall dataset. During analysis, very frequently and very infrequently used words (*i.e.* words above and below a threshold) are eliminated from consideration. A topic list of statistically significant words is then created.

iii) **Clustering documents** – A Naive Bayes classifier is used to assign document vectors and Vector Space Modelling is applied to plot documents in n-dimensional space (*i.e.* documents with similar topics are clustered around a central coordinate). The application of different vectors (*i.e.* topics) enables the relative positions of documents in n-dimensional space to be varied.

iv) **Creating the patent map** – The final n-dimensional model is then rendered into a two-dimensional map using a self-organising mapping algorithm. Contours are created to simulate a depth dimension. The final map can sometimes be misleading because it is important to interpret the map as if it were formed on a three-dimensional sphere.

Thus, in summary, patents are represented on the patent map by dots and the more intense the concentration of patents (*i.e.* the more closely related they are) the higher the topography as shown by contour lines. The patents are grouped according to the occurrence of keywords in the title and abstract and examples of the reoccurring keywords appear on the patent map. Note that there is no relationship between the patent landscape maps and any geographical map and that the map should be regarded as being a globular shape so that patents located at the top left hand corner of the map will also be relevant to those located at the bottom right hand corner of the map.

Please note that the patent maps shown in this report are snapshots of the patent landscape, and that patent maps are best used an interactive tool where analysis of specific areas, patents, applicants, inventors *etc* can be undertaken ‘on-the-fly’.

Appendix E Non-patent literature search

The NPL search was completed using access to *Web of Science*® which is a database operated by *Thomson Reuters* and is accessible through the *Thomson Innovation*[50] platform.

Web of Science® provides access to citation databases and also has multidisciplinary content covering over 12,000 journals worldwide, including Open Access journals and over 150,000 conference proceedings. There is retrospective coverage in the sciences, social sciences, arts, and humanities, with coverage to 1900[51].

Search NPL requires a different technique to searching patent databases and, as such, a simple search using some of the wording used in the earlier patent search was thought to be sufficient. The searching process has been kept simple and does not include many of the alternative terms used in searching patents.

This is represented below:

(3 NEAR D) or 3d or (three NEAR dimension*)) NEAR (Print* OR Fabricat* OR manufactur*))

The search was limited to publication years 2008-2013.

A separate search for additive manufacturing was also performed and merged into this first dataset:

ALL=(additiv* ADJ 2d ADJ Manufact*) AND (TF>=(2000) AND TF<=(2013)).

The search was also date restricted to 2000-2013.

This produced a file with 1066 “hits”

The current search has been date limited as it was not thought to be warranted, in the scope of the current project, to look at years earlier than 2008 in journal coverage. However, further analysis of such data could be useful in this area and could represent an area for further analysis.

[50] More information is available from http://info.thomsoninnovation.com/en/features
[51] More information is available from http://thomsonreuters.com/web-of-science/

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