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3D Printing and intellectual property futures

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Abstract

This report contains socio-legal research conducted on the relationship between 3D printing and intellectual property (IP) at the current point in time and in potential future scenarios, through the use of horizon-scanning methods in six countries—China, France, India, Russia, Singapore and the UK - to build a rich picture of this issue, comprising both developed and emerging economies.

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3D Printing and Intellectual Property Futures

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Executive Summary

This report contains socio-legal research conducted on the relationship between 3D printing and intellectual property (IP) at the current point in time and in potential future scenarios, through the use of horizon-scanning methods in six countries—China, France, India, Russia, Singapore and the UK - to build a rich picture of this issue, comprising both developed and emerging economies.

In conducting this research, we take up the baton from previous UK Intellectual Property Office (IPO) reports on 3D printing and IP (Mendis, Secchi and Reeves 2015). As noted in these previous reports, there is very little empirical research on how the relationship between 3D printing and IP is playing out in practice. In addition, there is very little existing literature or research on 3D printing's trajectory outside of developed Western economies, and how it is interacting with IP in the rest of the world. Our research goes some way to filling this gap, presenting novel insights on developments in Russia and Asia. Furthermore, as the UK reassesses its place in the world post-'Brexit' there is a need for greater awareness about future trade partners outside of the European Union (EU) such as the countries we examine.

In our project, we have collected valuable information 'from the ground' on the past and present of 3D printing and IP in these different countries. Another novelty of our project is the futures projections we led in each place, in order to understand potential trajectories going forward for 3D printing and IP, and to understand the extent to which a harmonised or fragmented global picture can be constructed. Our interdisciplinary, international team, combining legal, business and social scientific regional expertise on 3D printing, has used cutting edge and novel empirical methods in order to pioneer a deeper probing of the ramifications of 3D printing, going further than prior commentary through methodological innovation and an international focus on 3D printing and IP.

While we have created new research filling - to some extent - the gap on 3D printing and IP outside of Western countries, we also acknowledge one of the limitations of our work. The case of BRICS countries may not be representative of all developments in 3D printing and IP outside of Western countries. Indeed, the use of 3D printing is growing in the Middle East and Africa, but due to limitations of scope we were not able to conduct research in these locations. However, in order to build up a fuller picture of 3D printing's implementation globally, and the effect this may have on IP, more research is required in locations outside of the North/West.

This Report is structured in three parts: in Part I we present a summary of illustrative existing literature on 3D printing and IP; in Part II we present our empirical research on 3D printing and IP, including potential future scenarios; and in Part III we finish by outlining our findings, recommendations and conclusions drawn from both parts of our research.

Part I Existing 3D Printing and IP Literature

There is a blossoming body of literature from the business, legal and social sciences disciplines examining various aspects of 3D printing and/or IP. In the business and social science literature, topics including adoption, industrial applications, prosumerism, IP and future forecasting feature. The legal literature review covers each IP right in turn, proposals for new sui generis rights, enforcement, how different industries have engaged with 3D printing and IP issues, and potential future scenarios.

Much of this existing scholarship comes from and focuses on 3D printing and IP in the Global North/West, with limited material on emerging economies and the Global South. Furthermore, the IP literature mainly concerns copyright and patents, with literature on other IP rights less developed.

Part II Empirical 3D Printing and IP Research

In this project we have aimed to get away from the idea that futures—including for IP—are dependent on, or determined by, technologies or that they are simply derived from the ways in which the present is unfolding (Birtchnell and Urry 2016). In our empirical research we have aimed to better understand the potential future direction(s) of 3D printing technologies and what impact this may have for IP.

In order to understand more fully the development of 3D printing in different locations, especially in emerging and non-Western economies, its relationship with IP law and practice, and how this relationship may change in the future, we conducted qualitative focus-group style horizon scanning workshops with experts from the 3D printing ecosystem during 2017 and 2018 in six locations: Moscow (Russia), Roorkee (India), Singapore, Shenzhen (China), Paris (France) and London (UK). The workshops comprised between five and fifteen experts in each location who were selected because of their experience in 3D printing and associated industries and/or IP law and practice. Our aim was to get participants comprising a cross-section of different actors in the 3D printing/IP ecosystem, including across a range of industries.

The horizon scanning format for the workshop was developed by the project team and comprised three parts: the Multi-Level Perspective (MLP) to establish past and present trends and a combination of Ideal Futures scenario constructing and backcasting to scan the horizon. The benefit of the fusion of these methodologies is a multi-dimensional appraisal of foreseeable trends across different countries at different scales.

Part III Recommendations and Conclusion

Our main findings from the horizon scanning workshops comprise the following:

Commonalities across the countries

1. There are a number of similarities across the countries, in particular government policies to stimulate the creation and take-up of new technologies including 3D printing.
2. 3D printing does not appear to be posing fundamental threats to IP in any of the countries examined at this moment in time.
3. IP is far from the only area of law involved with 3D printing, and may not be the most important legal concern for those operating in the 3D printing industry. Medical device regulation, product liability, and health and safety laws may be more important legal considerations for industry actors.
4. But IP is also not unimportant for 3D printing as can be seen from patenting activities, the expiry of patents leading to greater technology dissemination and the possibility of more IP litigation.
5. The relationship between 3D printing and other emerging technologies such as automation, Internet of Things (IoT), artificial intelligence and blockchain is one of cross-fertilisation.

Country-specific issues

6. In Singapore, an ageing population is influencing government policy, and in turn influencing the implementation of 3D printing in medicine through government investment in this area.
7. Political and cultural trends especially in the UK and France seems to be leading to renewed interest in re-invigorating manufacturing within the nation-state and 3D printing is imagined as a technology which can fulfil these promises by achieving onshoring— but it is far from clear that this is realistic given competition from Asian and other Western economies.
8. The projected future outlooks for 3D printing and IP vary quite significantly among the countries examined: the Asian countries and Russia are broadly aligned with a capitalist future outlook, which would likely preserve 'conventional' IP laws and practices. The future outlook for the UK and France diverges from this picture by opening more possibilities for commons-based scenarios which may challenges conventional IP.
9. India remains a possible site for a future large manufacturing paradigm change given pre-existing conditions and significant potential for 3D printing in there. India could be the site of pioneering localised and distributed manufacturing, a model which may be adopted elsewhere especially in other parts of the Global South.

Our Recommendations

1. Developments should continue to be monitored, especially:
    - the extent to which 3D printing is successful in reinvigorating national manufacturing agendas;
    - the practical opportunities 3D printing offers for localised manufacturing in contrast to the current situation of a 'World Factory', containerisation and cyclic consumerism;
    - cultural and political trends;
    - country-to-country and sector-to-sector differences
2. The rise of China, and the potential rise of India into the ranks of developed economies with large middle classes exhibiting a strong showing in innovation, including in 3D printing, should be monitored.
3. We did not find a pressing need for legal reform from representatives of the industries participating in the horizon scanning workshops, including the creative industries, medicine, law, industrial manufacturing and research. Nevertheless, we recommend legal clarification of existing theoretical IP issues exposed by 3D printing. These issues include the subsistence of IP rights, identifying activities which constitute infringement especially secondary infringement and how some exceptions to infringement operate. The limited litigation so far on 3D printing internationally has not been on these topics and accordingly has not provided this clarification.
4. The UK should continue to keep track of any next steps in the EU arising from the European Parliament's Resolution on 3D Printing, and consider aligning any revisions of its own laws with the outcome of this process where this meets domestic objectives.
5. Companies should not be left alone to the task of business model innovation when faced with new forms of digitised technologies such as 3D printing. Instead, Government should work with industry to create transition 'champions' who would help companies understand the arising technological, economic, social and legal issues and rethink their business model to achieve long term competitiveness. Since such issues are only going to become prevalent as 3D printing technologies advance and becomes increasingly adopted, this may well become a critical aspect of industrial policy.

Introduction

3D printing, also known as 'additive manufacturing', is a novel manufacturing process which is being applied and utilised in various sectors. These applications vary from sector to sector and from country to country and create a complex picture for the process's different uses and evolving impacts.

3D printing has attracted a lot of media attention in recent years, especially after former US President Barack Obama in his 2013 second term State of the Union address emphasised the possibly critical role of 3D printing in strengthening manufacturing, scientific, defence and energy sectors. The strong potential of 3D printing was earlier noted by Karlgaard (2011), publisher of Forbes magazine. In particular, Karlgaard conjectured that 3D printing would become the 'transformative technology of the 2015–2025 period'. Likewise, Anderson (2012), Wired Editor, speculated that the 'desktop manufacturing revolution […] will change the world as much as the personal computer did'.

However, 3D printing has also been accompanied by a great deal of hype in the media and in public discourse (Birtchnell et al 2017), which is important to distinguish from 3D printing's commercial - and commons - reality. A major impetus for what one scholar has termed the 'hysteria' around the technology is the real or perceived potential for it to enable 3D printing both at the residential and commercial levels (Finocchiaro 2013). The capacity for consumers to own or access 3D printers is as a result of the proliferation of affordable fused deposition modelling (FDM) technologies arising partly from the expiry of patents originally developed by the US firm Stratasys. FDM involves the melting and extrusion of polymer (plastic) wire or filament via a heated nozzle and movable platform (build tray) or robotic arm. An open source FDM kit, the RepRap, fuelled various for-profit 3D printers by firms including MakerBot, Up!, Ultimaker, 3D Systems and others (Wittbrodt et al 2013).

According to its current technical limitations 3D printing is not in a position to replace the presently dominant system of subtractive manufacturing: bulk volume production in large-scale factory complexes. Beyond rapid prototyping and tooling (for example, moulds) 3D printing excels in the provision of custom or limited-edition objects and parts for end-user products, in some cases with geometric complexities or material innovations, which are difficult to match in conventional bulk volume factory-based tooling. Notwithstanding the creation of novelties, another option is for 3D printing to co-exist within, and co-evolve with, the current system. 'Lower volume parts with highly disruptive setups will favor DDM, regardless of relative cost, and high volume parts will favor traditional manufacturing' (Sasson and Johnson 2016: 88). Here 3D printing will plug in to existing business models, adding flexibility to manufacturing, simplifying distribution, and enlisting consumers into the product's lifecycle.

So while 3D printing may not yet be pervasive or fully supplant previous subtractive methods, it is still being used in different industries and by different kinds of people for different purposes. Accordingly, these uses vary from sector to sector and from country to country. Our research aims to build a richer picture of these uses, and their implications for intellectual property (IP), both at the present time and in potential future scenarios. In doing so, we take up the baton from previous UK Intellectual Property Office (IPO) reports on this topic (Mendis et al 2015).

As noted in these previous reports, there is very little empirical research on how the relationship between 3D printing and IP is playing out in practice. In addition, there is very little existing literature or research on 3D printing's trajectory outside of developed Global North/Western economies, and how it is interacting with IP in the rest of the world. Our research goes some way to filling this gap, as we conducted research in China, India, Russia and Singapore as well as in the UK and France. Indeed, in order to foresee the changes that 3D printing may bring about to IP, it is important to consider both types of economies. We suggest that markets involving these countries may be where 3D printing will have the most impact. As the UK reassesses its place in the world post-'Brexit' there is a need for greater awareness about future trade partners outside of the European Union (EU).

In our project, we collected valuable information 'from the ground' on the past and present of 3D printing and IP in these different countries. Another novelty of our project is the futures projections we led in each place, in order to understand potential trajectories going forward for 3D printing and IP, and to understand the extent to which a harmonised or fragmented global picture can be constructed. Our interdisciplinary, international team, combining legal, business and social scientific regional expertise on 3D printing, has used cutting edge empirical methods in order to pioneer a deeper probing of the ramifications of 3D printing.

While we have created new research, filling to some extent the gap on 3D printing and IP outside of Global North/Western countries, we also acknowledge one of the limitations of our work. The case of BRICS countries may not be representative of all developments in 3D printing and IP outside of Global North/Western countries. Indeed, the use of 3D printing is growing in the Middle East and Africa, but due to limitations of scope we were not able to conduct research in these locations. However, in order to build up a fuller picture of 3D printing's implementation globally, and the effect this may have on IP, more research is required in locations outside of the North/West.

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Part I Existing 3D Printing and IP Literature

In exploring the status of 3D printing and IP laws, and their potential future relationships, we conducted this literature review in order to set the scene for our empirical research in Part II. This review comprises two sections. In Section 1, an overview of the literature from business and social science disciplines on 3D printing and IP is set out. This is then followed by Section 2, a review of the legal literature on this matter.

1 Business and Social Science views of 3D Printing and IP

1.1 3D printing adoption

Recent works on 3D printing and digital manufacturing have highlighted the transformative effects of these technologies. 3D printing has been called a disruptive technology (Petrick and Simpson 2013; Lipson, 2014; Kothman and Faber 2016) and, as with other disruptive technologies such as the PC and Internet, has had some issues with its initial adoption (Eisenberg 2013; Rayna and Striukova 2016). Though 3D printing technology was originally developed in the 1980s, it went through several stages of adoption before starting to become disruptive (Rayna and Striukova 2016).

At first the technology was used primarily for prototyping; later (in the 1990s) it started to be used for rapid tooling, mainly to manufacture customised gigs and moulds. In the late 2000s, due to the decreasing prices of 3D printers and the increasing quality of printing, 3D printing started to be used for direct manufacturing – fabrication of final products (or at least parts of such products). The fourth stage of adoption started in the 2010s and has involved consumers designing and manufacturing their own items using 3D printers they either own, or can access locally, for instance in makerspaces and FabLabs (Rayna and Striukova 2016).

Overall, the adoption of 3D printing technologies has been affected by both their advantages and the challenges they bring about (Mellor et al 2014). Several research papers have discussed the advantages of 3D printing over conventional manufacturing techniques. 3D printing makes products flexible and easily customisable (Holmström et al 2010), which allows companies to manufacture products to suit customers' needs and desires (Wong and Eyers 2010; Huang et al 2013) and makes production of prototypes, as well as customised products economically attractive (Holmström et al 2010; Berman 2012; Mellor et al 2014). 3D printing also helps to increase products' functionality (Holmström et al 2010; Huang et al 2013). This is particularly important for industries such as the hearing aid industry, where customisation and design changes are required regularly and which have traditionally involved a high amount of manual labour (Holmström et al 2010). Overall, it means that 3D printing has the potential to solve the dilemma between product variety and unit costs (Oettmeier and Hofmann 2016).

3D printing also makes it possible to produce complex designs, which could not have been manufactured otherwise (Mellor et al 2014). For example, objects, which would be traditionally produced as several subcomponents, can be manufactured as a single piece (Holmström et al 2010). Also, since grids or even hollow structures can be produced, 3D printing makes it possible to create objects which are lighter in comparison to those produced using traditional manufacturing methods (Petrovic et al 2011).

All this is possible at no extra cost, which means that product design can be modified easily and the volume of production could be increased if needed without extra investment (Berman 2012; Weller et al 2015; Rayna and Striukova 2016). Other advantages include reduced material waste and energy consumption (Holmström et al 2010; Huang et al 2015), shortened time-to-market, just-in-time production (Huang et al 2015), the possibility of being environmentally friendly (Campbell et al 2012) and the reduced cost of manufacturing (Holmström et al 2010; Karunakaran et al 2010).

While the advantages of using 3D printing are numerous, there are also challenges associated with its adoption. These challenges include: high capital investment (the cost of machines); poor (but increasing) range of materials and their high cost; low printing speed; the need for more robust and user-friendly software to handle designs; and the need for standards and certifications of products, processes and materials (Mellor et al 2014; Rylands et al 2016; Arcos-Novillo and Guemes-Castorena 2017). Moreover, using 3D printing requires some knowledge of different materials and their properties, some knowledge of specialised software as well as some object design and finishing (e.g. post-treatment) knowledge (Rylands et al 2016).

1.2 Industrial applications

As 3D printing technology matures, it has started to be introduced in many industries, such as aerospace, automotive, medical, construction, and jewellery. A number of studies discussing the process of implementation of 3D printing have been published. For example, Kothman and Faber (2016) examined the application of 3D printing in the construction industry and commenced by looking at 3D printing's possible positive effects. For instance, customising a house using traditional construction methods adds 40% to its cost, whereas using 3D printing in customising houses would bear no extra cost. It also means that the role of architects – usually used only by the richest – could become more significant, with more people using their services. Also, the cost of houses could be reduced even further, as there is a 50-60% waste reduction when 3D printing technology is used. Kothman and Faber (2016) also mention that at the moment integrating pipes and wires is still done by hand even when using 3D printing; however, once installation of heating systems, insulation, running water and electricity becomes automated in the future the speed of construction will be significantly increased. Yet, at the moment there are several limitations which prevent 3D printing from disrupting the construction industry. First of all, the quality of materials needs to be improved, as well as the printing accuracy. Secondly, certification and standardisation processes need to be put in place.

Sandström (2016) studied the adoption of 3D printing by the hearing aid industry from 1989 to 2008. His findings suggest that 3D printing permitted improvements in both quality and productivity. First of all, using 3D printing for producing shells means that, unlike in the past, employees do not have to be exposed to toxic smells and fumes. Furthermore, in addition to lowering the cost of manufacturing by automating many of the processes, 3D printing technology helped make better quality products. Prior to the use of 3D printing, hearing aid manufacturing suffered from quality problems and was not standardised. Also, 3D printing entailed the shortening of some processes from one hour to five minutes, with half the amount of people making four times as many shells as before. Finally, 3D printing permits the manufacture of a great variety of (complex) shapes which improves the comfort and acoustic fit of the aids. The manufacturing process has also been made more efficient as digital blueprints of the shells could be stored electronically, making it possible to create a copy without a new impression. Overall, however, 3D printing technologies did not have a disruptive effective on the industry, as the barriers to entry are still high due to the importance of reputation and other complementary assets which incumbents have (Sandström 2016).

Finally, Deradjat and Minshall (2017) studied the application of 3D printing in dentistry. The authors conducted interviews with representatives of six companies which use this technology in their processes, and found that though using 3D printing could help improve some of the process, especially related to customisation, there are still numerous challenges which exist. These challenges are mainly related to technology immaturity, product design issues and quality assurance. Deradjat and Minshall (2017) also state that implementing 3D printing in the dental industry is much ‘trickier’ than in the hearing aid industry due to the complexity and variety of the models.

In addition to studying the adoption of 3D printing by different industries, Beltrametti and Gasparre (2018) also investigated the adoption of industrial 3D printing at the regional level in Italy. Based on 48 in-depth interviews with a combination of stakeholders (e.g. entrepreneurs, managers of technology supplier companies, early adopters in the manufacturing sector, service-provider companies specialised in additive manufacturing, ‘makers’), they find that the most prevalent usage of 3D printing in Italy is still rapid prototyping, with only a few sectors, such as aerospace and biomedical, where end-use parts directly manufactured with 3D printers are becoming increasingly common. In addition, developments are currently under way in a variety of sectors, such as the automotive industry, the dental industry, and the jewellery sector. Aside from these sectors, however, Beltrametti and Gasparre (2018) note that there is still no sign of a ‘manufacturing revolution’ in the consumer goods industry, mainly because of 3D printing’s lack of competitiveness in comparison to other manufacturing technologies. They emphasise that such a ‘revolution’ in the consumer goods market may well never happen, unless a ‘technological quantum leap’ occurs.

1.3 Potential industrial impacts

Not only does 3D printing have the potential to disrupt various industries, but it may also disrupt general processes, such as supply chains (Bogers et al 2016), product warranties, component upgrades, repairs, and recalls (Kietzmann et al 2015). In particular, 3D printing can potentially improve the efficiency of supply chains (Petrick and Simpson 2013; Wittbrodt et al 2013; Liu et al 2014; Kohtala 2015), reduce shipping and storage costs (as the need for storage of multiple items with unpredictable demand will be minimised and import duties will be reduced (Khajavi et al 2014)) and shorten delivery lead times (Liu et al 2014). Supply chain management can also potentially have an improved dynamic, as many steps will be digitised and compressed (Kothman and Faber 2016).

3D printing technologies can also have a potential impact on society more generally, especially beyond the concerns of using this technology for printing illegal items such as guns. At the individual level, 3D printing can help businesses produce better tailored products, especially related to medical care, where specific characteristics and patient needs could be taken into account and the cost of the treatment could be reduced (Huang et al 2013; Huang et al 2015).

1.4 3D printing and sustainability

A possible impact of 3D printing on business is its ability to enable sustainable manufacturing (Ford and Despeisse 2016), thereby promoting the shift towards a circular economy (Despeisse et al 2017) and global sustainability (Gebler et al 2014; Chen et al 2015). A window of opportunity for commercial 3D printing is in the area of sustainability. A like-for-like comparison of additive manufacturing with the existing system of subtractive manufacturing provides inconclusive evidence, for instance in energy use in production per se, although models taking into account the entire manufacturing lifecycle appear to offer an assessment framework (Watson and Taminger 2018). Once alternatives in distribution and consumption are taken on board there are key differences with additive manufacturing that potentially make it more sustainable (Chen et al 2015).

There are three key areas where 3D printing may provide gains in sustainability, namely, improved resource efficiency, extended product life and reconfigured supply chains (Ford and Despeisse 2016). Advantages emerge in product redesign, material input processing, component and product manufacturing, product use, repair and remanufacturing, and recycling. Resource efficiency is plausible in the actual process of additive manufacturing in material input processing. Whereas subtractive manufacturing creates waste within the process of reducing a material feedstock into an object or part, additive manufacturing allows more control over the amounts of material that are fed into the system with consequences for waste management (Griffiths et al 2016). Only the structures, or scaffolds, holding objects in place constitute waste and, in some processes, such as those with beds of polymer or metal powder, scaffolds are not required. Upcycling of waste materials is also viable with metals while less so for polymers, wood or other materials suffering from purity and quality issues in recycling. Even before the product is 3D printed, design innovation offers sustainability advantages through the extension of products' lives. With online shopping already the norm in the Global North, so-called make-to-order business models are already a reality, and locally sited 3D printers are an attractive alternative to inventories and the additional costs to suppliers and consumers of misdeliveries. Here, plausible scenarios for consumers include replacement or modular parts to repair objects themselves with 3D printed pieces, thereby reducing the need for waste handling and processing. Supply chains are also a key focus area for sustainability with the present system relying on transoceanic containerisation and energy inefficient inventories supported by road and rail transport to position products near to consumers in stores or to their doors (Sasson and Johnson 2016).

1.5 The adoption paradox

As could be seen from the above, and also as noted by Ford et al (2016), the impact of 3D printing technologies is extremely broad. However, despite the possible positive effects on the economy and society, the adoption of 3D printing technology has been relatively slow. This could be explained by the technical limitations of 3D printers as well as a lack of skills needed to operate them (Berman 2012; Gibson et al 2015). If these are indeed the reasons, adoption could be sped up through the growing number of 3D printing services (Rogers et al 2016), which could include both design and manufacturing (Rayna et al 2015).

Roth (2018) adopts a different point of view to explain this adoption paradox. Arguing that 3D printing has, in fact, existed in different forms since at least the beginning of the 19th century, Roth (2018) proposes that the relatively slow adoption of the technology may be due to a confusion between form and medium and advises that, to unleash the full potential of 3D printing, suppliers of 3D printers should focus on selling the process of 3D printing instead of the machines. For Roth (2018), '[t]he cash is in the medium, not in the machine', which means that business models must be reconsidered to achieve a 'golden moment'. Indeed, 3D printing and additive manufacturing have the potential to reconfigure business models and promote open and user innovation (Rayna et al 2015; Rayna and Striukova 2016). The advent of 3D printing has also provided fertile ground for open communities that can be incorporated in innovation strategies (West and Kuk 2016).

1.6 Prosumerism and co-creation

As 3D printing technologies provide possibilities for users to start producing goods at home (Fox 2013; Eyers and Potter 2015), many of them could be expected to become 'prosumers' (Rayna et al 2015). Not only is 3D scanning - allowing the exact replication of objects - becoming more widely available (D'Aveni 2015), consumers can now also transform digital data into physical objects, and consequently remix physical products in order to achieve any degree of personalisation (Rindfleisch et al 2017). What is more, printing household items with a 3D printer could potentially lead to savings of about US$1000 per year (Wittbrodt et al 2013). The results of another study by Steenhuis and Pretorius (2016), who surveyed 200 3D printing users from various online 3D printing forums, which showed that 82% of owners of home 3D printers are satisfied with their 3D printer purchase, are not surprising – despite the fact that 60% of owners report that the 3D printer is somewhat or very difficult to use.

Overall, the first consumers who have adopted 3D printing could be categorised as 1) 3D tinkerers who use 3D printing to repair existing products; 2) 3D creative consumers, who are modifying the properties of existing products; 3) 3D designers, who create new products altogether, but do not create new functional experiences (e.g. coat hooks, doorknobs), and finally 4) 3D inventors who introduce new functionalities and new experiences to the products they create (e.g. Handie prosthetic hand and Cortex cast) (Kietzmann et al 2015).

Despite the initial adoption of 3D printing technologies by individuals, traditional manufacturers do not yet see consumer 3D printing as a threat, because the quality, variety of colours and materials of current consumer 3D printed products is lower than what is offered by traditional manufacturing (Steenhuis and Pretorius 2016). However, with consumer 3D printing improving steadily and taking into account various advantages offered by 3D printing, it is unavoidable that more and more consumers will start manufacture items at home (Steenhuis and Pretorius 2016).

In addition to becoming prosumers, users also become co-creators (Rayna et al 2015), by both co-designing and co-manufacturing items with companies. Not only may this phenomenon result in the development of new products and services, but it may also help the integration of low-income consumers from developing economies into the global market (Maric et al 2016). In addition to co-creating with companies, consumers also use 3D printing technologies to co-create with other consumers. The early adopters of 3D printing have supported this sharing mentality, for instance by sharing their designs via online platforms, posting videos with their progress on video-sharing sites and sharing their experience on online forums (Kietzmann et al 2015).

These new types of consumers potentially mean business challenges for companies (Rayna and Striukova 2016), as well as legal and policy challenges (Kietzmann et al 2015). The challenges they bring about are intensified by the fact that in order to create or co-create using 3D printing, one does not necessarily need to own a 3D printer. Institutions such as makerspaces and FabLabs have emerged to bridge this gap and provide wider access to the 3D printers. Since 3D printing enables prototyping products at a relatively low cost, as well as manufacturing small runs of production without incurring the high-tooling costs associated with mass manufacturing, it is expected to have a transformative impact on entrepreneurship. This is indeed the question that is explored by Mortara and Parisot (2018). In particular, they investigate how FabLabs and similar spaces enable entrepreneurship by transforming ‘makers’ into entrepreneurs. Using a grounded approach, Mortara and Parisot (2018) find that, indeed, such spaces foster entrepreneurship by reducing both the fear of failure and the performance threshold. This is because 3D printing and the other technologies available in such spaces allow would-be entrepreneurs to ‘learn the skills and establish a correct set of routines to grow and survive’. Moreover, Mortara and Parisot (2018) emphasise that FabLabs and similar spaces enable ‘high learning speed’, which plays a critical role both at the beginning of the venture process (to understand the key features of the products and how to manufacture them) and at a later stage (to test the market and decide whether to scale up their operations). In addition to encouraging entrepreneurs, an ecosystem of makerspaces/hackerspaces, driven by open source hardware, may make it possible for consumers (especially in developing countries) to develop solutions that serve their needs (Maric et al 2016).

1.7 3D Printing and IP

There is the spectre of 3D printing and associated online repositories becoming the ‘next Napster’, a trend that would see printable files disseminated on the Internet as easily as digital music files were in the 1990s and 2000s with consequences for profit-making and creative recognition and control. The household level is indeed the most fraught for IP enforcement concerns. Commercial spaces are more regulated and presumably less susceptible to IP violations. Yet, here a major consideration for IP is the role of patent expiry in the 3D printing space with scale arising from commercial interest in exploiting open designs first from FDM and more recently with Selective Laser Sintering (SLS) and Stereolithography (SLA) (Gao et al 2015).

As such, there are no logistical or technical reasons for commentators to foreclose the capacity of the future Internet (or similar global communication systems) to be in a position to afford consumers the ability of sharing or trading 3D printable designs online, particularly when approaching near-infinite, zero-latency bandwidth; that is, with neither delay in transmission nor limitations in file size (Bell and Walker 2011). However, uncertainty is observable at present in the scope of the physical technology of 3D printers to deliver products to the standards consumers expect and in accordance with current cycles of product evolution, reinvention and replacement. Indeed, ‘citizen empowerment’ through household 3D printing is constrained by the current technical aspects and competencies (Ratto and Ree 2012).

Current limits will need to be surmountable across a number of dimensions for 3D printers to become ubiquitous at the residential level for users who do not have the acumen or patience of hobbyists (Johan 2013). First, there is the scale of the object, which is determined by the physical dimensions of the 3D printer. There are no current examples of 3D printers being able to cater to residential settings for products with dimensions beyond $50cm^2$. Here the onus is on design innovation and consumer assembly, although since the advent of flat-packs and part modularity there are ways 3D printers could provide parts that are easily, or even automatically, assembled. Second, there is product colour. Different colours entail multiple batches of plastic powder or wire, or post-production processing in the form of coatings of paint. Third, the surface ‘finish’ of 3D printed objects is unique with roughness being the norm due to the layering of materials, and post-production processing again being required for smoothness. Fourth, the mixture of materials is limited with plastic and resin being possible in residential settings and metals, wood and minerals available in industrial and commercial ones. Fifth, the speed of the process and the complexity of knowledge required to be able to print useable objects is not to be underestimated. Finally, data security is a key threat in the development of systems requiring users to take on board testing or development roles in the home (Do et al 2016).

If 3D printing did become ubiquitous in residential settings, accompanied by online repositories with limited regulation and accountability, it would represent a serious challenge for policymakers: a veritable 'Pandora's box' (Olla 2015). Social and economic policy puzzles along these lines require new techniques and strategies. Some options for regulators include education that promotes community collaboration and peer-to-peer (P2P) learning; accountability along the lines of recent moves in other forms of digital content in music, video, and literature; and methods of tracking and collating data, such as social network analysis (SNA) (Heemsbergen et al 2016). The challenge arising from the implementation of such strategies cannot be overestimated since there is a risk that innovation and adoption might be discouraged, or stymied, and incumbents unduly privileged.

If corporate responses to media piracy and sharing over the past decades offer a bellwether then the challenge of P2P networks and ubiquitous 3D printing could either be potentially restrictive 'kneejerk' enforcement strategies or 'the development of standardized protocols of reduced complexity that encourage adoption by consumers who possess a reduced technical proficiency' (Appleyard 2015: 76). IP law and enforcement are in a position to learn from the implementation of standards for 3D printing, as mapping shows interventions can either support or hinder innovations (Featherston et al 2016).

Some legal commentators recommend companies proactively aim to secure IP rights through registration and the strict monitoring of online repositories and P2P networks (Esmond and Phero 2015). Such approaches take for granted that consumers in the future will be the same as today. A defining feature of human ingenuity is the ability to make things to use or trade. Prior to the 20th century in the developed world the idea that consumers were also producers was to state the obvious for the majority of the population: before the Industrial Revolution many citizens were 'prosumers' who could create household objects themselves or access localised production services in the form of networks of craftspeople.

With technologies automating labour in various guises this idea of the 'prosumer' is once again becoming mainstream and commentators are couching a 'new industrial future' on the horizon (Birtchnell and Urry 2016). Consumers across sectors are providing labour into the products they consume ranging from the self-assembly of flat-packed furniture to scanning consumables via an automated check-out. 3D printers intimate the possibility of taking this trend much further in allowing 'digital prosumers' the capacity to provide input into the design elements and physical production processes (Ritzer and Jurgenson 2010). The emergence of digital prosumers does not necessarily sound a death-knell for major corporations once IP is taken into account. Analysis of markets led by 3D printing suggest that major brands' monopolies would profit from capturing surplus from prosumers, chiefly through the enforcement of rigorous IP regimes (Weller et al 2015). It is possible to imagine 3D printing as underpinning regional revival in deindustrialising regions through creating knowledge economies able to materialise the IP produced in SMEs, makerspaces and research hubs, and universities committed to playing a role in this transition could be catalysts (Birtchnell et al 2017). One factor for IP is the scope for prosumers to disrupt or transgress organisational rationality by refusing to 'prosume' according to expected routines (Chen 2015).

1.8 3D printing and business futures

Given the uncertain path or paths 3D printing may take, several attempts have been made to forecast the future of 3D printing. For example, Jin et al (2017) believe that the medical industry is currently a hotspot for 3D printing and more medical applications will appear in the near future. Another hotspot is the pharmaceutical industry, which was initially rather resistant to the adoption of 3D printing; however, since the first 3D printed drug (Spritam) was approved by FDA in 2015, more research is being conducted in this area (Ben-Ner and Siemsen 2017). The authors also believe that industries such as hearing aids and spare parts are likely to be disrupted by 3D printing in the future, as they have a high variety of products, high demand for customisation and individualised products and a need for redistributed local production.

In another study Jiang et al (2017) apply a Delphi method to gather the views of 65 academics and industry experts about the future of 3D printing. Four areas – production, supply chain and localisation; business model and completion; consumer and market trends; and IP and policy – were considered. According to the study, the impact of 3D printing is more likely to be felt in the areas of supply chain (especially with spare parts being printed by end users), possible emergence of new forms of IP and (illegal) file sharing.

Another Delphi study which was conducted by Kaivo-oja et al (2018) investigates 3D printing in Finland and Europe using a foresight approach. Based on a study of 100 emerging technological cases in Finland, they find that while by 2025 many 'new technological breakthroughs relevant for 3D printing and industrial revolution' will have happened, many bottlenecks – related to skill gaps, uncertainties of existing efficiency potential, feasibility of 3D technologies, transition management models and associated path, legal constraints, and risk and threats associated with 3D printing systems and technologies – remain. Furthermore, uncertainties related to the availability of materials, and their sustainable use, the adoption and diffusion rate of new 3D printed products, and IP rights issues make it very difficult to build a roadmap of market development through 3D printing. Finally, in regard to innovation policy, Kaivo-oja et al (2018) assess four different long-term scenarios ('global economy', 'local standard', 'sustainable times', 'focus Europe') and identify the 'local standard' scenario – which entails a decrease in globalisation, low integration of EU policies – as the most favourable development from a 3D printing adoption perspective.

While there are great expectations that 3D printing will lead to extensive changes in our economies, and numerous businesses across a wide range of industries have begun to look into the benefits the use of 3D printing could provide them, our understanding of the actual changes brought about by these new digital manufacturing technologies is still limited.

1.9 Forecasting IP's Role in 3D Printing's Ubiquity

Horizon scanning is a useful window into how 3D printing could become ubiquitous in both residential and commercial settings. A useful recent horizon-scanning exercise engages with the utopian political imaginaries around 3D printing across both domains and establishes three distinct scenarios: maker-as-entrepreneur, economic revival of the nation state, and commons-based utopia (Stein 2017). Despite fostering divergent futures in terms of the societies imagined, the political imaginaries position 3D printers as a transformative innovation with the capacity to radically revise current global systems of mass-manufacturing, supply chains and retail. Similarly, a forecasting exercise utilising a matrix of two axes of uncertainty, local/global and capital/commons, proposed four scenarios: netarchical capitalism, distributed capitalism, resilient communities and global commons (Kostakis et al 2016). Here 3D printing emerges as ubiquitous within polar extremes of advanced capitalism from a model where IP is enforced rigorously and according to profit maximisation to one where IP contributes to socio-environmental equality and egalitarian principles.

An indicative residential forecasting effort is the scenario ‘Willow Pond’ where an off-grid low-carbon utopia foresees the transformation of home garages into collaborative makerspaces. Here additive manufacturing functions in energy efficient systems made sustainable by circular economies of disassemblers that recycle objects into parts and materials for 3D printers and assemblers (Tonn and Stiefel 2014). There are also dystopic imaginaries possible for 3D printing, for instance, the innovation providing impetus for anti-feminists or white supremacists to exercise prejudices through illicit or demeaning object production: personalised sex dolls or unregulated firearms (Fordyce 2015).

In the commercial domain efforts to quantify the impact of 3D printing on global distribution systems by 2020 suggest profound reductions in costs in the life sciences and automotive sectors for custom implants and spare parts inventories (Bhasin and Bodla 2014). Yet, it is unclear how this would interface with, replace, or render redundant the status quo. One proposal is the design global-manufacture local (DG-ML) model imagining commons-based peer production scaling up in response to degrowth and sustainability shortfalls in the present system (Kostakis et al 2015). Those countries currently off-grid from transoceanic containerisation systems due to a lack of infrastructure, political unrest, or geographical isolation represent a growth area for 3D printing with potentially vast new markets resting in these areas in future (Rauch et al 2016). Certain industries will benefit from 3D printing’s affordances: for instance, pharmaceuticals (Lind et al 2016). The prescriber of drugs and medicines, or the pharmaceutical companies, could replace the pharmacy in direct relationships with the patients. Patients might even 3D print their own prescriptions in the home. Here regulation would interface with safety concerns deriving from the misuse or misinterpretation of prescriptions by patients or by exploitation of consumers by companies.

2 Legal views of 3D Printing and IP

At the current point in time, there is a growing body of literature on the interaction of IP and 3D printing. There are very limited overviews of law and 3D printing, with Daly’s introductory work (2016) on 3D printing a notable exception, examining IP alongside product liability, data privacy and firearms laws. Other literature has examined one particular area of law (e.g. Record et al 2015), and within IP law, often one particular area of IP within one or a couple of particular jurisdictions (e.g. Scardamaglia 2015). Much of this existing scholarship focuses on the position of Global North jurisdictions, with the Global South jurisdictions’ position when encountering 3D printing highly under-researched.

Here we outline the existing legal literature, by type of IP right, calls for reform (including the creation of sui generis rights), enforcement issues and industry-specific encounters with 3D printing. Some legal authors have also pointed to possible future scenarios for 3D printing and IP, which we also note.

As can be seen below, much of the existing literature on 3D printing and IP comes from developed Western jurisdictions (US, UK, EU) and pertains to copyright and patents. The literature on trade marks, design rights and trade secrets, and from non-Western jurisdictions, is less developed. One limitation of this part of the literature review is that we mainly searched for English-language literature on 3D printing and IP. We acknowledge that more literature may be available in other languages, particularly for non-English-speaking jurisdictions.

2.1 By jurisdiction

2.1.1 International

There is some international harmonisation of IP law in the form of the WIPO-administered Berne Convention and Paris Convention, and the WTO TRIPS Agreement. Khoury (2015) has noted that very limited material exists on the interaction of TRIPS and these WIPO treaties with 3D printing. One article can be found in WIPO's magazine (Malaty and Rostama 2017) which offers some brief analysis of the application of TRIPS and the Berne Convention to 3D printing.

Bi- and multilateral trade agreements are another vehicle by which IP rights can be harmonised, such as the ultimately ill-fated ACTA agreement, and the Trans-Atlantic Trade and Investment Partnership (TTIP – which seems to be abandoned or indefinitely put on hold) and the Trans Pacific Partnership (TPP) (Daly 2016). In the Pacific Rim, the Regional Comprehensive Economic Partnership (RCEP) is under negotiation between the 10 ASEAN governments and China, India, Australia, Japan, New Zealand and South Korea, and includes IP as a topic. Given current geopolitical events, the international trade space in the coming years may end up assuming a more Chinese character (Daly and Thomas 2017). What, if any, effect a pivot to China in the international trade agenda may have on IP more generally, and 3D printing more specifically, remains to be seen. However, the changing geopolitics of trade may also have a profound effect post-Brexit on the UK which is currently looking beyond the European Union to other trading nations such as India and China (Phillips 2017; Swinford 2017).

WIPO itself has acknowledged the relationship between 3D printing and IP, including in its 2015 report, where it named 3D printing as one of three 'frontier technologies' along with nanotechnology and robotics which had the potential to boost future economic growth. In this report, WIPO presented data from first patent filings, showing that this activity has been concentrated in a few countries (US, Japan, Germany, France, UK, South Korea and China). The Russian Federation is ranked sixth in first patent filings, but India is not even in the top 20 countries. While the US, Germany and Japan accounted for most early patent filings, China has been a recent and prolific addition to this group of countries, especially its universities and public sector organisations. Currently, the US receives most patent filings, followed by China and the rest of Europe, followed by middle-income countries (e.g. Argentina, Malaysia, South Africa). The Report points to the potentially different trajectory for 3D printing in developing economies and remote areas, which may not be stops on existing globalised supply chains, although developing economies may also have less need for the labour-cost-savings that 3D printing may bring, in environments where human labour costs are currently low.

The WIPO report also acknowledges the important role open innovation approaches have played in 3D printing's development, but also the potential of low-cost personal 3D printing to render the enforcement of existing IP rights more difficult, for reasons including the difficulty in identifying individual infringers, the possibility that infringers may be customers of the IP rightsholders, and the cost of enforcement. The Report draws on the experience of online copyright infringement to suggest certain strategies for rightsholders: changing their business strategies e.g. from the 3D printer market to secondary market for supply materials; and embracing users' infringing behaviour rather than trying to fight it by creating a feedback loop between users and the brand owner to create better products and boost brand loyalty. Yet WIPO acknowledges that the rate of personal 3D printing infringement is still small compared to digital copyrighted material for reasons including the immaturity of the 3D printing market, the lack of ease of use of 3D printers and materials.

As regards WTO-matters, the Swedish Kommerskollegium (National Board of Trade) issued a report on 3D printing and trade in 2016, which included some discussion of IP rights. It considered that TRIPS applied to 3D printing, while acknowledging that TRIPS only provides a minimum standard of protection and domestic laws provide much of the substance of IP laws and must be assessed separately. The challenges 3D printing presents to IP rights, and the complexities brought about by these divergent national laws, according to the Kommerskollegium (2016: 31) 'will become more evident and hence so too will potential inadequacies within the system. This in turn might create a need to re-examine national systems and TRIPS.'.

2.1.2 National and regional jurisdictions

As can be seen from the material below, much of the existing literature in English on 3D printing pertains to the US, EU and specifically the UK. There is also fairly comprehensive literature on 3D printing and IP law from Australia e.g.: Scardamaglia (2015) on trade-marks; Rimmer (2016) on copyright; Liddicoat, Nielsen and Nicol (2016) on patents; and Adams (2015) and Berger (2019) on design rights. Rimock (2015) has examined 3D printing's implications for Canadian IP law. These jurisdictions' approaches are not considered in detail because they are beyond this project's scope. This current literature review comprises a summary of the academic literature from the US and EU on 3D printing and IP law. There is a small but growing body of literature in the Chinese language on 3D printing and IP, with a few articles in English on this topic. At a glance, this body of literature suggests that there are similar issues and concerns among Chinese IP scholars as Western scholars regarding how existing legal frameworks apply to 3D printing and how appropriate they are for this new reality (see e.g. Liu and Yu 2015).

2.2 Copyright

Different elements of the 3D printing process may form a point at which copyright subsistence occurs: the code of the 3D printing design file; the design contained within the file; and the physical object to be printed (Daly 2016). Despite harmonising measures such as the WIPO treaties and TRIPS, there are still many divergences in how different jurisdictions determine the circumstances in which copyright can subsist, exceptions to copyright infringement, and situations of intermediary liability.

2.2.1 Copyright subsistence

From an EU and British perspective, Mendis (2014) considers that it is possible that the CAD file itself is capable of being protected under copyright law, and Bradshaw et al (2010) consider that in domestic UK law a CAD file would fall within the definition of literary works which includes computer programs and 'the preparatory design material' for a computer program. However, the situation in the US suggests that CAD files would not be protected by copyright due to the creative-functional distinction in US IP law. Simon (2013) considers that CAD files are dictated by functional considerations and at least there should be a presumption against them enjoying copyright protection. However, Grimmelman (2014) disputes this characterisation, given the ‘function’ of such files is to produce (potentially) copyrightable objects, and even then, software is copyrightable in the US, so in his view the CAD files would enjoy copyright protection. If the CAD file contains the design of an object which is not protected by copyright e.g. a functional item, or a sculpture now in the public domain, the CAD file will not enjoy protection itself (Menell and Vacca 2016).

There is also no consensus on whether the design for the eventual object would be protected by copyright. There are even differing views within certain legal systems about what the situation would be here. For instance, in the US, Simon (2013) considers that 3D printing designs may be protected under US copyright law as ‘technical, mechanism, engineering or architectural drawings’. However, Weinberg (2010) considers that the question in US law turns on whether the eventual object to be printed is a creative object or a functional object: in the former case, the design may attract copyright protection, but not in the latter case. The problem of objects with both functional and creative aspects exists, where a ‘severability’ test is performed, by which any decorative elements of the object that exist beyond the scope of the useful object can be protected by copyright. In the UK, the graphic design contained within a CAD file is likely to constitute an artistic work but it is also likely to constitute a ‘design document’. Making an article to a design document, or copying such an article, unless it is a design for an artistic work (e.g. a sculpture), does not constitute copyright infringement, but it is possible to infringe copyright in the making of a design document.

The 3D printed object itself may also attract copyright protection. US law recognises a broad category of sculptural works enjoying copyright protection, but excludes ‘useful articles’. Again, the severability test will apply to those objects with both aesthetic and functional aspects. In UK law, sculptures and ‘works of artistic craftsmanship’ are considered to be artistic works capable of attracting copyright protection; case-law has excluded industrial prototypes from the definition of sculpture. However, it has been argued that some of these objects may be insufficiently original to attract copyright protection in their own right if they have been constructed based on a 3D printing design file (Simon 2013), although there is no consensus on this point. Another issue may be that they are 3D representations of 2D items protected by copyright, and so their construction may potentially infringe copyright in UK law at least (Bradshaw et al 2010).

Scanning 3D objects to create CAD files, which can then be sent to a 3D printer to print a new object, merits specific attention. Although IP’s treatment of ‘reverse engineering’ has been a topic of discussion predating 3D printing (Samuelson and Scotchmer 2002), 3D scanning may make this practice much more prevalent. It seems that the position in US law would be that scans of physical objects would either not be sufficiently original to attract copyright protection in their own right (Weinberg 2013); whether copyright subsists will depend on whether the original object is ‘creative’ or ‘useful’. The UK law position would seem to be that if an object is scanned and there is no real element of creativity, then the CAD file produced is also unlikely in itself to attract copyright protection (Daly 2016; Mendis 2014). 3D printing CAD files will also fall within the definition of a ‘design document’, and in UK law the copyright in such a document is not infringed by making an article from it (although there may be design law aspects); case-law suggests that any copyright in the original document will not be infringed by the creation of a 3D printing file using a 3D scan of the object created from the design document (Bradshaw et al 2010).

2.2.2 Exceptions to infringement

Although this debate also pre-dates the emergence of 3D printing, the existence of the 'fair use' defence to copyright infringement in the US (and various other jurisdictions, such as South Korea and Israel) does set a different standard of permissibility compared to the more limited 'fair dealing' defences in jurisdictions such as the UK and Australia. Given 3D printing's potential for remixes and mash-ups of objects, it may be that these would be more permissible under fair use conditions than in fair dealing conditions, but this remains to be seen in practice.

2.2.3 Intermediary liability

It is acknowledged that the experience with digitising technologies such as the Internet has profoundly shaped contemporary copyright law, including intermediary liability regimes (Osborn 2016). This can be seen by the use of these intermediary liability regimes in the 3D printing sphere. For instance, Digital Millennium Copyright Act (DMCA) takedown notices have been received by 3D printing intermediaries such as Thingiverse. Some prominent – and controversial (given it was not always clear that copyright infringement had actually occurred) cases include the Penrose Triangle (Rideout 2011; Weinberg 2013), Warhammer fan-art (Brean 2013), the Tintin rocket (this is the strongest case for copyright infringement actually occurring – Daly 2016), Michelangelo's statues (Rimmer 2017), and Marcel Duchamp's chess set (Rimmer 2017).

Due to the changes to copyright brought about by the Internet and digitisation, statutory intermediary liability regimes such as contained within the DMCA exist for copyright, but do not exist for other kinds of IP rights in US law, which may make it attractive for rightsholders to frame their claims within the DMCA even if it is another right (e.g. trade mark or design right) which may be infringed. However, the Katy Perry/Left Shark saga – in which takedown notices were issued by Katy Perry's lawyers but not complied with given disputes about whether copyright actually subsisted in the first place – demonstrates that there is some fightback against inaccurate assertions of copyright (or 'copyfraud'), the overuse of takedown notices and the chilling effects they may produce (Rimmer 2017). The EU position differs from that in the US, with the E-Commerce Directive providing a broader scheme of intermediary service providers' liability for illegal acts of users including patent and trade mark infringement. However, given many of the large transnational platforms are either based in the US and/or operate under US law, the lack of DMCA equivalent safe harbors and notice and takedown schemes for patents and trade marks has an impact going beyond US borders.

Shapeways, a prominent 3D printing marketplace and print-on-demand service has been pro-active on the issue of takedowns, with a section in its Content Policy devoted to this issue, which includes the opportunity for users to make counter-claims (Weinberg 2015). Shapeways has also started publishing annual 'Transparency Reports' giving information about how the company deals with IP disputes and third-party access to user information (Weinberg 2017). The main findings from Shapeways' 2016 report are that:

- IP-related takedown requests almost doubled in 2016;
- 20% of trade mark claims were withdrawn after low levels of scrutiny;
- The number of notices of combined copyright-trade mark claims declined.
  The most recent Shapeways transparency report (2017) revealed that the number of combined copyright-trade mark claims remained steady compared to 2016.

Rimmer (2017) has suggested that a 'moral panic' exists around 3D printing facilitating copyright infringement. This would seem to be borne out in part by Reeves and Mendis' research commissioned by the UK IPO (2015) which found that for the British industries they surveyed, there was not currently a strong threat to their business models and IP from consumer 3D printing, although this might change in the future.

2.3 Patents

WIPO (2015) has identified a prominent role for patents in 3D printing's history by the early inventors, given many of them started companies based on their inventions and later commercialised them, however for WIPO it is unclear how important patents may have been to prevent rivals from imitating the technology.

Since an application must be made for a patent, there is more certainty around what is patented and what is not, unlike the situation with copyright. In terms of enforceability of patents and infringement, prior to 3D printing, the difficulty in constructing a patented invention (i.e. time, cost and skill) was an 'architectural' constraint to patent infringement (Brean 2013; Desai and Magliocca 2014). Yet 3D printing may entail that it is easier to make patented items, including by those who do not realise that they are engaging in infringing conduct, leading to a possible increase in the number of 'innocent' patent infringers (Weinberg 2010).

The patentability of parts of the 3D printing process has attracted relatively little attention, especially compared to the detailed discussion in copyright. Van Overwalle and Leys (2017) note that '[h]ardly any discussion seems to have taken place in case law and in academic literature on the principle of patentability of 3D printing methods, printers or printer components, nor on meeting the patentability standards of novelty, inventive step/non-obviousness and industrial application/utility', and these seems to be largely uncontroversial topics from a patent law perspective in practice. More problematic may be the patentability of materials involved in 3D printing especially as regards fulfilling the criteria of novelty and inventive step/non-obviousness. CAD files themselves do not seem to qualify as patentable subject-matter. The 3D printed object produced may be patentable if, for instance, it is a totally new and novel object. Pearce (2015) has developed an open source algorithm to generate prior art for 3D printing materials which could be used to evaluate published patent applications for obviousness, and thus operate as a means for restricting 'any overly broad patent using vague, generic, formulaic and combinatorial claims'.

Exceptions to patent infringement have been a topic of discussion vis-à-vis 3D printing in the US and UK. In particular, the exceptions for repair have featured. US law ensures that many cases it will be legal to manufacture replacement parts for a patented item so long as the part itself is not covered by a specific patent and the repair does not constitute a 'reconstruction' (Wilbanks 2013). Weinberg (2010) considers that replacing parts of a patented item in a way which gives it a new or different functionality would not constitute patent infringement in US law. In UK law, there are exceptions for private, non-commercial purposes (as in many other European jurisdictions) and also for 'experimental purposes relating to the subject-matter of the invention'. However, the fact that manufacturing an invention from scratch is considered to infringe patents in UK law, and this being interpreted in case-law as undertaking a comprehensive refurbishment of an item, may create problems for creating spare parts for a patented item using a 3D printer, including whether mash-ups or remixes of patented items would be viewed as a kind of remanufacture (Mendis 2013).

As regards intermediary liability, there is no US equivalent of the DMCA safe harbors and notice and takedown schemes for patents. In US law, 3D printer or scanner manufacturers are unlikely to be held liable for contributory infringement since the equipment is 'dual' or 'multi' use (Daly 2016). The situation for file-sharing sites is less clear and may have to be clarified via litigation (Desai and Magliocca 2014). Van Overwalle and Leys (2017) opine that as long as a site did not receive a takedown request and 'did not remain wilfully blind towards possible infringing content on its site' it should not be liable for indirect infringement under US law. Holbrook and Osborn (2015) consider that the sale of CAD files which facilitate patent infringement should be recognised as itself constituting infringement in US law, but that extending liability to those making or possessing more generally such files may have adverse 'chilling effects' on innovation and so would not be a desirable outcome. Brean (2015) disagrees with the latter view, and believes that liability should extend to CAD files. The printing out of a patented object, including by an intermediary such as Shapeways, would constitute patent infringement (Van Overwalle and Leys 2017).

In the EU too, infringement claims against intermediaries may be attractive due to the difficulties and expense in identifying and pursuing direct infringers (Ballardini, Norrgard and Minssen 2015) – although Osborn (2016) considers that 3D printing may result in more attempts to sue end-user infringers. In UK law, supplying the 'means relating to an essential element of the invention' will give rise to infringement. Mendis (2013) posits that the supply of a CAD file to make an item which infringes a patent may constitute supplying 'means', while Bradshaw et al (2010) consider that more may be required e.g. supplying a 3D printer, raw material and the design file.

Mimler (2013) has considered the position of German patent law vis-à-vis 3D printing. He notes that it is similar to UK patent law since both are based on the Community Patent Convention, although courts in the two countries have sometimes differed in their interpretation of these provisions. Mimler's analysis suggests though that the German law would operate in a similar way to UK law as regards 3D printing and patent infringement.

There has been some discussion of possible modifications to patent law as a result of 3D printing, such as the introduction of a private printing exception to infringement in the US (Desai and Magliocca 2014), and a Digital Millennium Patent Act (Doherty 2012).

2.4 Design Rights

Design rights have been considered one of IP rights' 'poor cousins', at least compared to copyright and patents, but this status may be changing due to 3D printing (Berger 2019). A CAD file itself will not be protected by European design rights, but it may contain proprietary designs. Margoni (2013) has criticised EU design law as largely neglecting the needs of 3D printing and its designers, especially those involved in Open Design initiatives, because of the tools created by EU law being designed with more attention paid to industry sector rather than to designers themselves.

In the EU, both EU-level and national systems have registered and unregistered design rights. The UK's design rights system is now fairly similar to the EU system (Waelde et al 2013). Bradshaw et al (2010) have considered the UK law position as regards 3D printing and design rights and in their view many items would not be protected as registered designs due to provisions which prevent products whose features are solely dictated by 'technical function' from being protected, and the 'must fit' exception. 3D printed spare parts are likely to fall within these exceptions (Parikh 2016). Exceptions to infringement comprising a private and non-commercial use exception and fair dealing exceptions may exempt an important part of 3D printing activity from infringing registered design rights. Intermediary liability for the infringement of registered design rights e.g. for file-sharing sites is unclear especially as regards the operation of these exceptions (Daly 2016; Mendis 2013).

Unregistered design rights in UK law also have a 'must fit' exception. There is no explicit personal and non-commercial use exception but it would seem that unauthorised non-commercial use would not be infringing (Bradshaw et al 2010). Mendis (2013) considers that sharing unauthorised design files which on file-sharing sites would constitute infringement unless done so for non-commercial purposes; file-sharing sites which profit in some way from file-sharing activities may be liable for secondary or indirect infringement. Detection of such infringement and proof of copying (which is needed to establish infringement liability for unregistered design rights) may prove to be obstacles to a rightsholder asserting their rights.

Schovsbo and Nordberg (2017) have noted the 'external' limits of European design rights, in the form of competition law's provisions against the abuse of a dominant position, and fundamental rights, which may operate in practice as providing additional exceptions to design rights infringement.

In US law, 'design patents' are the analogous right to design rights in Europe and other jurisdictions such as Australia. Katz (2016) considers that anyone who downloads an unauthorised CAD file and makes an object from that file would be an infringer, along with anyone else who makes, uses, sells, offers to sell or imports an article covered by a design patent. There is a lack of clarity in US law as to whether someone who sells a CAD file which infringes a design patent would be liable as a direct infringer, and also unclear is the legal situation of the unauthorised creation or use of a CAD file which replicates a protected design, although Katz believes that future courts may well find such actors liable for infringement. Osborn (2018) calls into question the very possibility of applying design patents to CAD files given it is not clear that they are 'articles of manufacture' for the purposes of US design patent law.

2.5 Trade Marks

Even if trade marks are used in some way during the 3D printing process, it may be difficult to find trade mark infringement occurring. This is due to trade mark owners' exclusive rights being related to the use of the trade mark as an indicator of source or badge of origin in the course of trade. Trade mark owners' exclusive rights can be asserted vis-à-vis others attempting to use the mark as an indicator of source or badge of origin in the course of trade, in a way which is likely to cause confusion to consumers. Even if trade marks are used somehow in 3D printing, this use may not qualify as being an indicator of source or use as a badge of origin in the course of trade. Furthermore, 3D printing, similarly to the situation with patents, may 'disturb the longstanding balance between the costs and frequency of infringement' in trade mark law (Ammar and Craufurd Smith 2015). Khoury (2015) has argued that the importance of brands as marks of origin may diminish due to 3D printing where everyone can print out objects themselves, thus placing the end-user in charge of creating the object and selecting the materials with which to make it. Osborn (2016) points out that one typical justification against infringing goods is that they are of a lower quality than authentic goods, but this may be disproven by 3D printing, in which case trade mark owners may need to focus their arguments not on the grounds of consumer protection or brand tarnishment but on the grounds of pure property rights in their trade marks.

The personal use of a trade mark or a use which is otherwise not in the context of commerce or trade to indicate source or origin is not likely to be an infringement (Daly 2016). For Weinberg (2010), 3D printing something at home containing a trade mark should not constitute infringement but as soon as that object was sold, even informally, then this would be a 'use in commerce' and so be infringing. Desai and Magliocca (2014) question whether this practice may constitute commercial use and so be infringing for the purposes of US law. Ammar and Craufurd Smith (2015) acknowledge that the precise meaning of use in trade or commerce is already 'hotly contested' and this is likely to intensify with 3D printing. They note that in EU jurisprudence, a more flexible reading of what constitutes 'use' for trade mark infringement purposes has been recognised, such that 'the use of a sign in relation to 3D printed goods that are identical to those for which the trade mark is registered is likely to be considered an infringement' but that the issue will remain as to whether the mark was used in the course of trade.

Trade mark dilution in jurisdictions such as US and UK seeks to protect the prestige of a (famous) trade mark and protect against those copying the mark and selling it, even where there is no confusion as to source or origin. Desai and Magliocca (2014) consider that the justification for US law's post-sale confusion doctrine – that unauthorised use of a trade mark can injure the trade mark owner even if no consumer confusion – is eroded by 3D printing because consumers may have less or no reason to think that the use of a trade mark was necessarily done by the trade mark owner, as a result of 3D printing.

In US trade mark law, the functionality doctrine operates to prevent the registration of functional shapes as trade marks. Desai and Magliocca (2014) consider that 3D printing may lead to more trade dress infringement claims (or unauthorised third party use of those marks) but may also make it difficult to establish trade dress protection for a particular product design in the first place because 3D printing may more it more difficult to show that the proposed trade dress has been subject to substantially exclusive use by the applicant as individuals could be printing these objects at home with a 3D printers.

Secondary or intermediary liability may also be difficult to establish because the intermediary must be shown to have 'used' the trade mark in an infringing way (Daly 2016). Ammar and Craufurd Smith (2015) consider that, because CAD files do not directly replicate the physical products protected by a trade mark and the likelihood that it would be difficult to establish that the provider of a CAD file sought to mislead users as to the origin of the file, infringement is unlikely to be established in EU law because the use of the mark in relation to the CAD file is unlikely to affect the essential function of the trade mark. The situation may be somewhat different for trade marks with a reputation. Contributory infringement against the creator of a CAD file which is then used to print objects which infringe trade mark law is unlikely to be established in current EU law. Ammar and Craufurd Smith (2015) do recommend that CAD files should be treated as goods or services for the purposes of trade mark law, in order to more readily establish infringement than would appear currently to be the case.

In common law jurisdictions, trade mark claims are often brought with claims as regards the tort of 'passing off' (or 'misappropriation' in the US). Passing off protects the goodwill of a trader from misrepresentation. Passing off only applies to non-private uses as others must be misled. Bradshaw et al (2010) consider that 3D printing may bring more claims for passing off, especially when a trader's goodwill in comprised in the distinctive shape of goods. However, if the public is not misled as to origin, passing off will not be established.

2.6 Trade Secrets

There is very little literature on the role trade secrets may play in the 3D printing context. WIPO (2015) acknowledged the increasing importance of trade secret protection, including for 3D printing, such as over 3D printing manufacturing processes. However, Osborn (2016) also argues that trade secrets covering physical items such as machine parts will be disrupted by 3D printing due to 3D scanning to permit exact reverse engineering, and the likely future development of cheaper metal alloy printers. He posits that trade secret owners may turn to contracts to protect their rights e.g. requiring purchasers to agree not to reverse engineer parts. Osborn argues elsewhere (2018) that files made publicly available will not qualify for trade secrets protection, nor in the situation that the output of the files are made publicly available even if the files themselves are kept secret.

2.7 Sui generis rights

Tran (2017) has argued that the current IP law model of copyright, patents, trade marks, and trade secrets ‘does not work with 3D printing’ due to various deficiencies with these rights (in US law at least) as applied to 3D printing. Instead he proposes a technology-specific ‘PrintRight’ which would include: a property right to exclude; immediate attachment at the moment of creation (as in copyright); and usefulness (as in patents). In other words, ‘PrintRight is the right to not have a person’s useful creation mass-produced by 3D printing without permission’ and comprises a ‘modified, combined version of copyright and patent’ with a suggested 7 year term. This is the author’s proposal for reform of (US) law but does not reflect the current status of the law, and also has not been taken up by law and policymakers as a possible policy. While the proposal may add some clarity and certainty, it is likely to encounter significant opposition including from those wishing to preserve the existing IP system.

2.8 Enforcement issues

Mennell and Vacca (2016) identify some enforcement issues for IP rightsholders in the 3D printing space, based on enforcement issues in digital spaces which predate 3D printing but which are also directly relevant given the use of digital distribution for files in the 3D printing ecosystem. They note that Internet-era legal developments in the US have ensured a certain measure of immunity from intermediary liability for copyright infringements for certain kinds of actor (e.g. Internet Service Providers, equipment manufacturers). Other issues include difficulties around detecting infringement in the first place and the low amounts of money being recovered from litigation not justifying enforcement costs.

However, Mennell and Vacca believe that there are ‘several distinctions between music file-sharing and CAD file sharing that point toward more robust private and public copyright enforcement’ including the possibility for larger commercial actors to be implicated in file-sharing e.g. of replacement parts, and the potentially greater interest of government to pursue certain actors, especially where their products also affect public health or safety.

Van Overwalle and Leys (2017) have argued that at least as regards patents, 3D printing does not present conceptual problems to the ‘very essence of patentability and infringement theories’ but that ‘the perceived problems with 3D printing seem to relate to the scale of the infringement, resulting from the eminent use of CAD files and their decentralization effect’ i.e. a problem of effective and efficient enforcement. However, this in turn may indeed pose problems conceptually, given the assumption that patent infringement will be too expensive for most, and that infringement is 'centralised' in the premises of well-known competitors, both assumptions that are challenged by 3D printing. However, Van Overwalle and Leys acknowledge that 3D printing would have to become much more widely used than currently for this to become a real-life possibility.

There are a few approaches to addressing IP enforcement concerns which are identified in the literature and explained in the following subsections.

2.8.1 DRMs

Technical enforcement of IP rights can occur via digital rights management (DRMs) and technical protection measures (TPMs) being applied to 3D printing CAD files, printing software and printing hardware. Menell and Vacca (2016) question the effectiveness of DRMs in the 3D printing space, as well as the limited effectiveness of the DMCA anti-circumvention regime in the US which expressly authorises reverse engineering of computer programs in certain circumstances and includes various exceptions including for encryption researchers. Osborn (2016) argues that DRMs will only protect against the activity of unsophisticated users, and their implementation should also ensure that legitimate uses are possible.

Rimmer (2017) has discussed the campaigns by Public Knowledge and the Electronic Frontier Foundation to petition the United States Copyright Office at the Library of Congress to provide an exemption to the prohibition on the circumvention of DRM/TPMs for access control technologies for 3D printer users to use non-manufacturer-approved raw materials for 3D printers. This petition was opposed by Stratasys and the Intellectual Property Owners Association. The result of this process was the Copyright Office (2015) granting a very limited exception as regards 'computer programs that operate 3D printers that employ microchip-reliance technological measures to limit the use of feedstock, when circumvention is accomplished solely for the purpose of using alternative feedstock and not for the purpose of accessing design software, design files or proprietary data'.

The UK IPO also has a scheme through which members of the public can submit a complaint regarding the implementation of TPMs which unreasonably prevent them from benefiting from a recognised exception to copyright infringement. Some other EU countries also adopted methods for addressing this issue after the implementation of the Copyright Direct (Favale 2008). It is unclear whether any of these mechanisms have been used for situations involving TPMs and 3D printing.

2.8.2 Licensing

Menell and Vacca (2016) recognise the transition in digital content markets, when the music and film industries 'ramped up their use of subscription, low-cost download, and other licensed distribution channels to attract consumers and compete with unauthorised distributors of their works', and suggest that product manufacturers and designers can deploy similar strategies to develop and control 3D printing markets. This strategy seems to be borne out in practice with toy manufacturer Hasbro entering into partnerships with 3D printing companies such as Shapeways and 3D Systems to bring its copyrighted toy designs and 3D printed customised products to consumers. Streaming services such as those provided by Authentise are emerging, whereby consumers can stream 3D printing design files but do not download or have full access to the file (Daly 2016).

Open licensing of IP is another model which can be adopted by rightsholders, and is the main approach in sites such as Thingiverse (Moilanen et al 2015).

2.8.3 Encryption

Encrypted files were a method used by some of the UK designers interviewed by Reeves and Mendis (2015) to protect their work from being infringed by others, but encryption was also used to conceal the possibility that these designers' work might be infringing the IP of others.

2.8.4 Levies

Schovsbo and Nordberg (2017) have suggested a private copying levy might be applied to 3D printing hardware and software to compensate IP rightsholders for copies made of their work. It should be noted that the UK currently does not have a private copying levy scheme, although most neighbouring EU Member States do have such schemes, including France (Kretschmer 2011).

2.9 Industry encounters

There is some literature on how specific industries are faring in the 3D printing-IP encounter. The majority of this literature so far either pertains to bioprinting or 3D printing in the cultural industries.

The IP right most suited to bioprinting is likely to be patents, although other rights may also be relevant (Minssen and Mimler 2017). Minssen and Mimler (2017) have identified different patent claims which may occur at different stages in bioprinting research: design patents (and design rights in Europe) for machines, methods and techniques used in bioimaging and CAD at the preprocessing phase; patents for bioinks at the production phase; and a post-production maturation phase in which 'additional patent prospects might emerge in advanced organ production'. Despite general prohibitions on the patenting of human organisms, Tran (2015) considers that bioprinting is patentable from a US law perspective (as current bioprinted tissues are functionally similar but structurally different from real human living tissues), with bioprinting process claims easier to patent than bioprinting product claims. Regarding the more normative question as to whether bioprinting should be patentable, Tran argues that patents should be granted for bioprinting process claims but not product claims, which 'aligns well with the current landscape of patent-eligible subject matter'. In the European and British context, Li (2014) has also investigated bioprinting and patents, considering that bioprinted tissue and organs may be patentable if they pass 'morality' tests (which seems to turn on whether the destruction of embryos is involved), and do not fall within the medical treatment exception in those jurisdictions. However, she questions whether patents over bioprinting will be socially desirable or 'result in market exclusivity which creates undue barriers to health', instead arguing that a new business model for developing bioprinting technologies is desirable such as a portfolio approach to innovation (including government funding and a prize system), public research design file pools including crowdsourcing, and corporate social responsibility of firms owning patents (including voluntary licensing schemes and international technology transfer). However, Minssen and Mimler (2017) implicitly question the extent of the problems patents may cause in this area, given they consider that many basic patents will have likely expired by the time regulatory authorities would be approving the first functional bioprinted organ, and they also point to the research and experimental uses exceptions which exist in various jurisdictions which would allow others to conduct research and clinical testing of patented bioprinted organs or tissue.

3D printing and scanning's implications for the fine art and antiquities markets relating to the unauthorised reproduction of copyrighted objects and the manufacture of counterfeits is noted by Cronin (2015). However, he also recognises that 'no copyright protection exists for the vast majority of objects we consider cultural property' due to the fact much of these objects' original copyright will now exist in the public domain. Nevertheless Cronin has noted elsewhere (2016) that assertions of copyright in public domain cultural artefacts have been made by the owners of these objects, and copyright is also sometimes asserted over authorised reproductions of such items by placing copyright notices on the objects. However, copyright would only attach to reproductions if there is a distinguishable variation from the underlying work and that it reflects the new creator's own intellectual creation.

For libraries – many of which offer 3D printing facilities to their members – Jones (2015) has explored their position as intermediaries whose users may infringe the IP of others, and recommends that libraries adopt an 'acceptable use' policy in order to balance protecting users' expressive freedom (especially in the US, where the First Amendment offers strong protection of that right) with the liability risks for the library due to possible illegal use. Specifically on the issue of copyright, Chan and Enimil (2015) view that libraries can minimise their risks of liability by, for instance, providing staff training on recognising CAD files which may be infringing (although identifying such files may be difficult for staff to do in practice), and by providing policies and instructions to users on possible infringing uses of 3D printers. They also note the exceptions in US copyright law for libraries and archives including the 'unsupervised copying' exception, which may also apply to 3D printing activities, and the 'fair use' exception that users may utilise in their printing as well. UK libraries also offer 3D printing services. While there is limited literature on this topic compared to the US, the Oxford University Radcliffe Science Library has a 'Printing Policy' that printing jobs submitted by science students and researchers in the university must follow, which 'explicitly restricts the reproduction of copyrighted material, weapons or other inappropriate items' (Bridle 2015). There are various fair dealing exceptions in UK law which may apply to users' 3D printing activities in libraries, depending on the precise circumstances, such as for non-commercial research or private study (JISC 2014).

As regards food printing, Li et al (2014) examined 3D printing using chocolate and copyright protection, and found that copyright would operate to protect 3D printed chocolate creations in the scenario they describe, but that such printing may in certain circumstances infringe the copyright of others. They also explored issues regarding the co-creation of 3D printed chocolate and intermediary liability for chocolate printing companies.

2.10 Future scenarios

Some authors in the IP space have begun to envisage futures scenarios for the relationship between IP and 3D printing, especially as regards the possibility of increased litigation and legislative reform.

If 3D printing becomes ubiquitous in homes and businesses, in a highly decentralised manner, existential threats may be posed to IP. Lemley (2014) has argued that 3D printing, along with other new technologies, will create a world without scarcity, where needed objects can be made on a decentralised basis for a low cost. The fundamental bases and rationales for IP may be undermined by 3D printing (e.g. Osborn 2016), or at least may need to be re-evaluated (Khoury 2015) such as the private and public domains; the idea of use; the long terms of protection; the assumption copying can be prevented; the nature of enforcement of IP rights; and the need to incentivise creation and invention.

IP rightsholders may lobby legislatures for changes to IP legislation to prop up their existing business models which may include tight regulation of the 3D printing industry (Syzdek 2015). To this extent, commentators have proposed new legal models, for instance Tran's PrintRight mentioned above. Yanisky-Ravid and Kwan (2017) argue that a new framework is necessary, whereby registration, imprinting and activity tracking of 3D printing is carried out in a way which balances the interests of IP rightsholders and government authorities with the general public's freedom to use 3D printers.

An opposing view comes from other commentators, such as Osborn et al (2015) who have argued that IP rights such as patents should actually be weakened by legislators (although not abolished) and this can be achieved by shortening the patent term, increasing patent maintenance or renewal fees and changing the strength of patents related to 3D printing.

Regulatory forbearance is a further approach discussed in this area. For instance, Thierer and Marcus (2016) advance the principle of 'permissionless innovation', whereby any policy or legislative reform as regards 3D printing should be ex post in character and focused on addressing actual, not theoretical, problems. This can be contrasted with the 'precautionary principle' to regulating new technologies, which Thierer and Marcus (2016) criticise as potentially undermining the innovative benefits associated with the implementation of new technologies. In practice, they suggest that various measures, including limiting the liability of 3D printing intermediaries and allowing insurance markets space to innovate such as offering products to protect against IP-related claims, should be adopted.

However, the perceptions of 3D printing's disruptive effects may not match the current reality (Schneider et al 2014). Van Overwalle and Leys (2017) consider that 3D printing's trajectory so far does not call into question the principles and rules applying to patentability (with the possible exception of CAD files' status), and while patent enforcement against hobbyists or platforms may prove difficult in practice, they also argue that the principles concerning the exercise of patent rights are not fundamentally questioned, and instead there is an opportunity to apply theories on the scope of rights and infringement with 'more nuance and precision'. Yet the potentially greater scale of patent infringement does present possible challenges to the patent paradigm, and particularly the innovation incentives, but that these challenges are not being realised in the current 3D printing scenario.

Future scenarios must also take account of the development of 4D printing (also known as programmable matter) i.e. the printing of material objects which can change in form and function after they are produced. The IP implications of 4D printing are largely unexplored but initial comment suggests it may make it difficult to identify the origins of products and add complexity to IP application and enforcement (Al-Rodhan 2014; Campbell et al 2014).

After setting the scene with this Part on existing literature on 3D printing, we now turn to the empirical component of this research project.

Part II Empirical 3D Printing and IP Research

Part II presents the findings from six workshops held in different countries and attempts to foresee different futures for IP across nation-states. The object here is not to make predictions about future societies and economies as if we could somehow time travel into the world of our successors, but rather to fine-tune policy towards attenuating major transitions that would otherwise be unforeseen by, and henceforth potentially disruptive for, the general public. By softening transitions that include alterations in those norms that are constitutive of people's everyday lives there is hope for fewer destabilising pressures and more easeful transformations for incumbents in, for instance, vested interest groups in the status quo: traditional 'subtractive' manufacturing companies or transoceanic freight services. Given global trade and the ways nation-states fathom economic growth—that is through tools such as gross domestic product (GDP), which equate cyclical accumulations of goods and services with 'performance'—are intimately nested within systems of production, distribution and consumption a transnational approach to 3D printing and IP offers a broader, if more ambitious, optic for scanning the horizon for this particular technological innovation.

In this project we have aimed to get away from the idea that futures—including for IP—are dependent on, or determined by, technologies or that they are simply derived from the ways in which the present is unfolding (Birtchnell and Urry 2016). In our empirical research presented here in Part II, we have aimed to better understand the potential future direction(s) of 3D printing technologies and what impact this may have for IP.

In order to understand more fully the development of 3D printing in different locations, especially in emerging and non-Western economies, its relationship with IP law and practice, and how this relationship may change in the future, we conducted qualitative focus-group style horizon scanning workshops with experts from the 3D printing ecosystem during 2017 and 2018. To test the methodology, we conducted a pilot workshop in Brisbane (Australia). Based on feedback from the participants and facilitators, we refined the methodology before employing it in six full workshops in the following locations: Moscow (Russia), Roorkee (India), Singapore, Shenzhen (China), Paris (France) and London (UK). The workshops comprised between five and fifteen experts in each location who were selected because of their experience in 3D printing and associated industries and/or IP law and practice. Our aim was to get participants comprising a cross-section of different actors in the 3D printing/IP ecosystem, including across a range of industries.

The horizon scanning format for the workshop was developed by the project team and comprised three parts: The Multi-Level Perspective (MLP) to establish past and present trends and a combination of Ideal Futures scenario constructing and backcasting to scan the horizon. The benefit of the fusion of these methodologies is a multi-dimensional appraisal of foreseeable trends across different countries at different scales. The approach affords backcasting to now from the year 2050 with awareness of prevailing discourses around 3D printing and IP. This is the first time that these methodologies have been combined, but MLP and Ideal Futures scenario constructing have been used separately in previous studies for other technologies.

We acknowledge that this approach has limitations. One limitation relates to the number of horizon scanning workshops we could conduct for this project, given time and resources. We decided to prioritise emerging economies (China, India and Russia) as sites of research, whose take-up and uses of 3D printing have hitherto been under-studied. We included 3 developed economies as points of comparison, and these were selected based on relevance to the project funder's environment in the case of the UK, and location of investigators in the case of France. The Singapore workshop was an addition to the original plan for workshops thanks to the interest of the British High Commission in Singapore in the topic, and also provided a point of regional comparison for the Asian emerging economies we intended to study. We did not include a workshop in the US, even though it is a prominent force for 3D printing. However, 3D printing in the US, including from a legal perspective, has been extensively studied (see e.g. Ventola 2014; Schneiderjans 2016; Choi 2018; Mendis, Lemley and Rimmer 2019) and we wished to concentrate on countries and regions which have been less studied so far, hence its exclusion from the empirical part of this project. We acknowledge that this is a limitation of the research.

Other limitations come from the choice of research methods. The MLP, due to its focus on macro, meso, and micro levels offers only a broad and abstract appraisal with only paltry heed paid to real world events and human endeavours. Here policy requires further input from qualitative social science involving case studies and ethnographic accounts. In addition, the MLP is an ideal type and in linking a progressive development of technology through time it backgrounds partial or subtle socio-technical transitions, for instance, those that occur without a window of opportunity opening across all dimensions. The method does not adopt a quantitative framing and is not able to model predictive or probabilistic visions with precision. Accordingly, it is still possible that unforeseen 'black swans' could alter the future dramatically, particularly in the technical aspects of 3D printing. We look forward to seeing further future research fill some of the gaps this project leaves.

1 Methods

1.1 Multi-Level Perspective (MLP)

1.1.1 Micro-Level: Niche mapping of elements

The first part of the MLP involved a scene-setting exercise aiming to build a micro-historical trajectory from knowledge that is not widely publicised globally. Here the language and structure of the MLP, an 'ideal type' ontology, was drawn upon in order to provide conceptual bulk to the later scenarios. Visual aids involving arrows on paper could be utilised effectively to map out regional histories on an x-y axis involving a time-line and scale on a whiteboard or large paper printout, which participants could then populate (Figure 1).

1.1.2 Meso-Level: Regime mapping of dimensions

The second group of tasks was to populate the meso-level, which is more stable and interlocking. Here attention was paid to how the existing system is set to be disrupted by accumulations of niches. There were six dimensions to map. The group of tasks here was to establish the windows of opportunity arising from the 'stable' socio-technical regime and give as many examples as possible regionally for each of the dimensions: Policy, Science, Industry, Culture, Technology, and Markets & User Preferences.

Figure 1 - The MLP technology substitution dynamic model (Geels 2012).

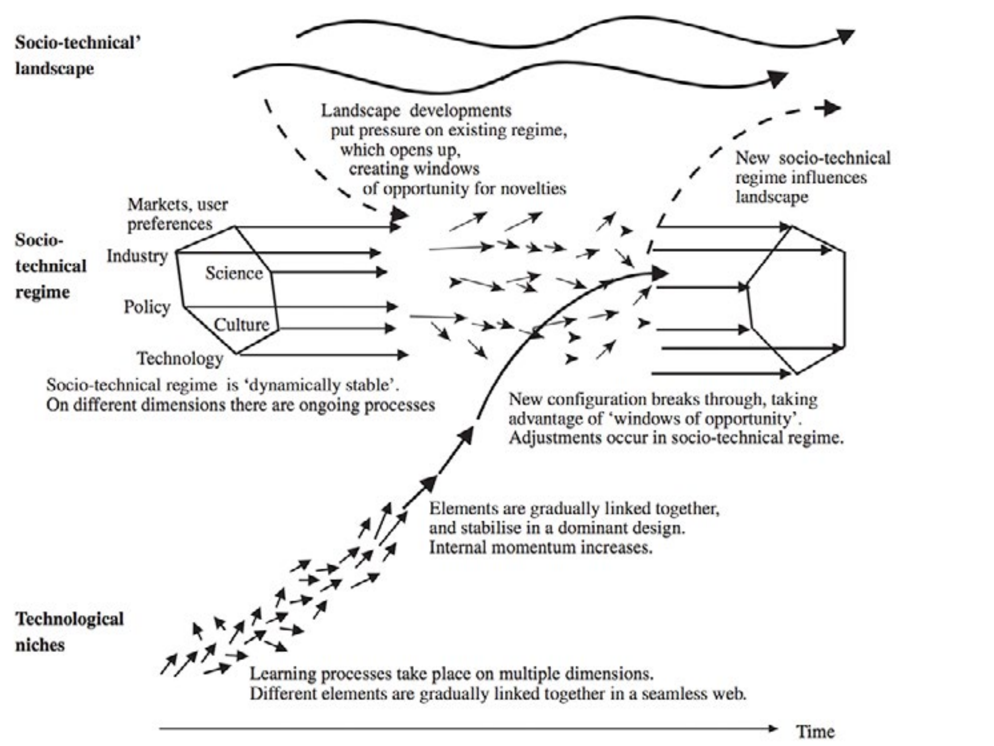


Fig. 1. A dynamic multi-level perspective on system innovations. *Source*: [15, p. 1263]

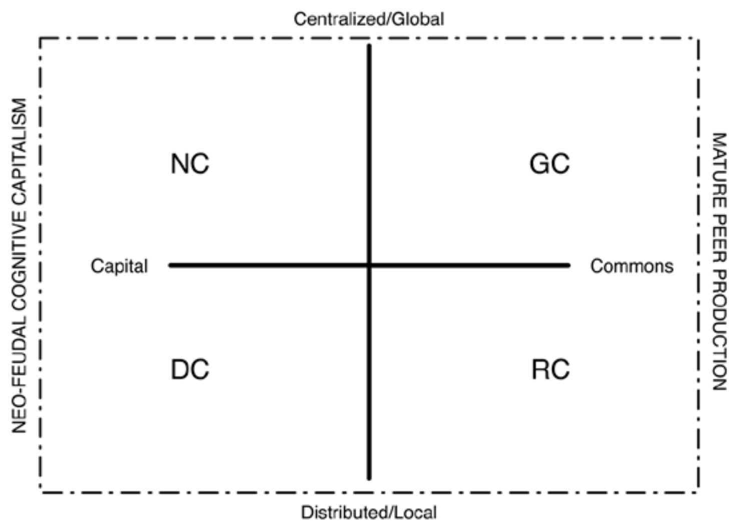
1.1.3 Macro-Level: Regime mapping of dimensions

The third group of tasks was at the highest level and involved participants assessing the various pressures through time that invoke 3D printing as a regime-changing novelty. Pressures occur at the niche level and regime and are instrumental in opening up windows of opportunity.

1.2 Ideal Futures

In order to construct an ideal scenario to backcast from for the countries, the two competing value models by Kostakis et al (2016) of neo-feudal cognitive capitalism (NFCC) and the hypothetical case of mature peer production (HMPP) were scrutinised using the abstraction of select dimensions from the MLP. These two contrasting models translate into two axes of uncertainty affording four possible polarised scenarios. The first uncertainty, on the vertical axis, is in whether technological control is centralised with an orientation towards globality or distributed technology diffusion with an orientation towards localisation. The second uncertainty, on the horizontal axis, reflects the orientation towards the accumulation of capital versus the circulation of technologies in the commons.

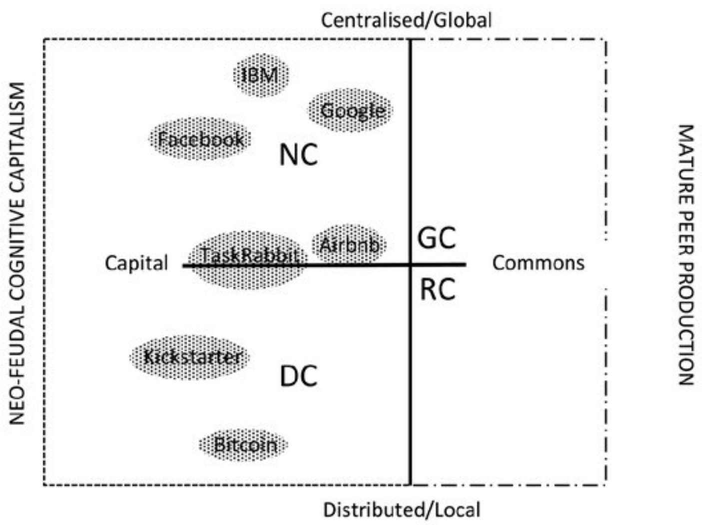
Figure 2 - Four quadrants from two axes: global/local & capital/commons (Kostakis et al 2016: 87).



Four future scenarios are adopted based on two axes of uncertainty developed by Kostakis and colleagues from work on the digital economy and 3D printing (Figures 2 and 3). The first top-down axis distinguishes centralised technological control (and an orientation towards globality) from distributed technological control (and an orientation towards localisation). The horizontal axis distinguishes a for-profit orientation (where any social good is subsumed to the goal of shareholder profit), from for-benefit orientations (where eventual profits are subsumed to the social goal). The polarisation between local and global is useful here in that we are discussing different regions in many cases with markedly contrasting notions of inclusion and exclusion in the global economy and in geopolitics. For instance, perceptions exist that Russia, India and China could be understood to be in conflict with many Western/capitalist ideals and IP can be typified by tensions between open source and over-regulation.

Netarchical and distributed capitalism differ in the control of the productive infrastructure but both are oriented towards capital accumulation and, thus, are parts of the wider value mode of cognitive capitalism. Here we find tech giants with centralised governance utilising the P2P infrastructures and user practices such as Google and Facebook, but also distributed types of P2P infrastructures with a profit-orientation such as Bitcoin and Kickstarter. Further, this side would include many of the rapidly growing businesses that appeared with the recent explosion of the 'sharing economy', whose very definition is still under debate. It is evident, however, that this term is also used to describe activities whose goal is clearly profit maximisation. Resilient communities and the global commons reside in the, one might say auspicious HMPP under civic dominance (right quadrants). Here, projects such as the free encyclopaedia Wikipedia, Free/Libre Open Source Software (FLOSS) and Open Source Ecology (OSE), in the upper right quadrant of GC are conjoined with RC projects and types of organisations of the commons such as the Transition Towns movement and permaculture initiatives as well as true sharing economy projects like time banks and food swaps whose goal is commons-oriented.

Figure 3 - Plotting of niches in each quadrant (Kostakis et al 2016: 87).



Participants were asked to 'flesh out' the four scenarios as ideal futures at radically opposed extremes, by plotting the various niches they chose from the previous stage (MLP) into each of the quadrants according to the niche's relationship to each axis of uncertainty. Once the quadrants were populated then participants were invited to start thinking about the possible milestones that could take place to get to each idealised future across the six trends of the MLP.

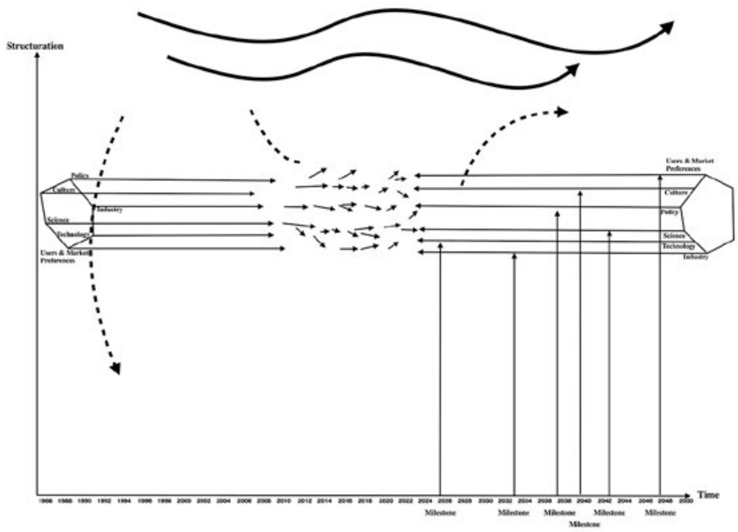
1.3 Backcasting

Backcasting has been implemented successfully for a range of academic, organisational and governmental purposes (see Banister and Hickman 2013 for a list). For the final exercise stakeholder-informed participatory backcasting was the primary method. The strategic objective was to understand how IP will be affected by ubiquitous 3D printing and this would form a constraint on the results of the scenario exercise. Backcasting involves 'looking back from a future where a desired goal has been met and creating decisive steps and pathways from that vision back to the present day' (Neuvonen and Ache 2017: 77).

‘To qualify as a backcasting study the scenarios chosen in the project must reflect solutions to a specified societal problem’ (Dreborg 1996: 816). This exercise entrusted in the stakeholders the responsibility of constructing pathways for attaining the vision gleaned from the second part of the workshop with the starting point being ‘the future’ (Timms et al 2014).

The task in this part was for participants to map pathways via milestones on the timeline for each of the four scenarios within each of the six dimensions (policy, science, culture, users/market preferences, technology, industry) from Stage 1, the MLP, back from the ideal, desirable future to the window(s) of opportunity identified in Stage 1’s timeline. For each of the dimensions the participants discussed stepping stones back to the regime change and form a concept of the configuration of the regime in its entirety.

Figure 4 - MLP and backcasting of four scenarios creates pathways for six dimensions (Geels 2012).



It was anticipated that each workshop would develop their own versions of the four scenarios flavoured by their region. From the different versions of the four scenarios, and different participant groups’ preferences for certain scenarios over others, we have been able to observe and assess the overall continuities and discontinuities of the different milestones imagined in each case through subsequent backcasting, and draw policymaking recommendations from these observations.

In the following sections, we present the information gleaned from each workshop, by detailing how participants engaged with each stage of the method described above. First we present the Multi-Level Perspective from each country, before presenting the Foresight and Backcasting exercises.

2 Multi-Level Perspective

2.1 China

2.1.1 Culture: Shanzhai

China has developed a specific, homegrown culture around making. Makerspaces have emerged in China, with the first being XinCheJian (新车间) which opened in Shanghai in 2010. In 2015, there were over a hundred makerspaces throughout China, with most located in large developed east coast cities (Saunders and Kingsley 2016). One important difference between makerspace culture in China and in the West is that makerspaces can be viewed as a less oppositional development to dominant manufacturing culture in China, where ‘many factories in China have long sustained their low-cost production through the open-source sharing of resources and ideas within a network of hardware manufacturers’ (Lindtner and Li 2010; Lindtner 2014). Maker culture in China exhibits specific Chinese characteristics, in particular the idea of ‘shanzhai’ (山寨) which has previously been used to describe the ‘copycat’ or counterfeit products made in the city of Shenzhen. Yet, more recently shanzhai has come to represent an alternative, self-reliant open innovation vision for novel and remixed products ‘created in China’, and has come to characterise Chinese makerspaces, in distinction to top-down Chinese Government ideas of a creative economy (Lindtner and Li 2010). However, public authorities also provide funding for some makerspaces which facilitates these activities (Saunders and Kingsley 2016). Overall, Lindtner (2015) argues that ‘China’s culture of making can neither be understood based on Western principles of copyright and intellectual property nor on Western histories of hacking’. Open innovation approaches, and the expiry of patents on 3D printing, have been viewed as key developments for the Chinese 3D printing industry.

2.1.2 Policy: Developing Chinese Innovation

The Chinese Government has adopted various policies over the last decade to stimulate home-grown innovation and the adoption of new technologies throughout the Chinese economy. On the topic of 3D printing, the Chinese Government issued a National Additive Manufacturing Industry Development Plan in 2015, which raised 3D printing techniques to the ‘national strategic level’ (Huang and Wang 2016). In 2017, eight national level policies had been launched by 23 departments of the Chinese government to support the 3D printing industry, covering manufacture, research and education sectors.

Part of China’s transition has included evolving attitudes towards IP: China has been viewed by the West as a ‘user’ of IP developed there, sometimes legitimately, but often illegitimately (Mehta 2007; Liu 2015). However, the Chinese Government has undertaken reforms of IP in Chinese law, although enforcement remains a challenge (Beebe 2014; Cao 2014; Holland 2017; Liu 2015) and also provided encouragement and incentives to Chinese actors to create and register their own IP rights. Nevertheless, China’s (perceived) lack of respect for others’ IP is one of the justifications used by US President Trump to impose tariffs on some Chinese goods in the current trade dispute between the two global powers.

These policies can be seen as evidence of China’s increasing self-assurance on the world stage, and its self-vision as a world power which is no longer economically at the service of the West, and instead is servicing its own people and developing trade relationships on its terms with other countries through the One Belt One Road initiative. Another recent example of this self-assurance is the National Sword policy restricting the importation of waste from other countries and causing repercussions in Western countries which are no longer able to export their waste to China and instead may have to deal with it in situ.

2.1.3 Industry: The World's Factory

In recent decades, China has emerged as the world's dominant manufacturing nation (Li 2017). Some Western countries, especially the US, have instituted policies around 3D printing and other forms of 'making', in part as an attempt to wrestle manufacturing away from China and its mass production as a form of 'insourcing' rather than 'outsourcing' (Garrett 2014; Stein 2017; Jackson 2017). Yet 3D printing is also present in China itself, and China has invested in the technology since the 1990s (Ford 2014). Moreover, particularly in the Chinese context, 3D printing and conventional forms of mass production cannot be separated, given China's capacity for mass manufacturing is also utilised to create actual 3D printing machines, which are then used within the country and transported to other locations globally, including the West.

2.1.4 Science: Education Policy

In order to create a knowledge economy and not just a manufacturing economy in China, education is being utilised to form a new generation with the requisite skills in this area, who, it is intended, will be creators and makers rather than just users, including as regards IP. Indeed, this can be seen in the Chinese Ministry of Education's 2017 Guideline of Comprehensive Practical Activity Curriculum in Primary and Middle Schools (中小学综合实践活动课程指导纲要), which encourages schools to procure 3D printers for students from Grades 7 to 9 to learn the principles of 3D printing technology, model building, and the human-machine interaction in the process of design. The objective of this policy is to start the formation of a future skilled workforce for the Chinese knowledge economy.

2.1.5 Markets and User Preferences: Home-Grown Firms

China, like India, has experienced the huge growth of the middle class in the last decade or so, with disposable income and a taste for consumer products, especially among the younger generation. For physical goods, Chinese consumers exhibit preferences for foreign/Western branded products particularly for food and medication, due in part to concerns about food safety and quality, which has again been thrown into relief by a recent scandal involving children's vaccinations.

However, for digital products and services, China has developed its own home-grown ecosystem, partly due to Chinese Government restrictions of Western/globalised firms such as Google and Facebook, but also partly due to Government economic support for a Chinese Internet industry. Indeed, some digital services in China are more developed and more prevalent than in the West, such as mobile payments, to the extent that in some hi-tech cities such as Shenzhen and Hangzhou (the home of Alibaba) consumers may find it difficult or even impossible to pay by cash in some shops and cafes. Indeed, the Chinese Government has encouraged some public services (paying utility bills, medical appointment bookings, checking social security information) to be integrated into WeChat and Alipay. As a result it is very difficult for foreign companies to compete with these local Chinese services.

The Chinese 3D printing ecosystem does present some differences from the globalised/Western ecosystem. Aside from makerspaces and 3D printer machine manufacturers (many of which export their products internationally), a distinct ecosystem is growing around service providers, particularly those with an online presence. Thingiverse's file sharing platform is the most popular and prominent site globally and in the West. However, in China prominent services including Simpneed and Mohou (which now offers English-language services), which are closer in form to Shapeways' file upload and print-on-demand service. China has also seen emergence of new and innovative 3D printing design service companies such as Xuberance in Shanghai, established in 2014 (Ma 2017), which would seem to be a prime example of the kind of innovative design digital manufacturing company Made in China 2025 aims to create and foster. In what may be a departure from the shanzhai ethic, Xuberance has developed 'an online and offline platform for digital copyright trading' in the form of digital models, which, it argues, demonstrates the 'different' business model for 3D printing in China compared to Western countries (Ma 2017). One of Xuberance's digital models, of a lamp, was traded to a Chinese company for 3.2 billion yuan (about US$480m), constituting 'the first case in the world of a 3D-printed product being traded with such a high value' (Ma 2017).

2.1.6 Technology: Made in China 2025

In a broader context, 3D printing technology is considered as one of the gateways to China's next generation social system, accompanied by artificial intelligence, big data, mobile Internet and the Internet of Things. Indeed, another major Government policy is Internet + (互联网+), which has various aims, including to 'digitise' manufacturing and integrate it into the Internet of Things (Keane 2016).

A further major Chinese Government policy is Made in China 2025, which has been compared to Germany's 'Industry 4.0' policy, and 'signals China's intention to launch an industrial transformation from labor intensive production to knowledge intensive manufacturing' (Li 2017). To do this, Li (2017) points to the main features of Made in China 2025:

> *The plan focuses on improving the quality of products made in China, creating China's own brands, building a solid manufacturing capability by developing cutting-edge advanced technologies, researching new materials, and producing key parts and components of major products.*

The digitised manufacturing features of Internet+ overlap with Made in China 2025. Both policies foresee the increased use of robots and automation in manufacturing (Brown 2017). 3D printing is also included in the Made in China 2025 policy, given one of the policy's goals is 'building a solid manufacturing capability via developing cutting-edge advanced technologies' (Li 2017; Huang and Wang 2016). Other aspects of Made in China 2025 which may pertain to 3D printing and associated activities are the desire for the design part of the manufacturing process also to take place in China or be 'Designed in China' (Li 2017), in contrast to the previous scenario where product design occurred in developed economies, and then those products were manufactured in China. Promoting home-grown design may entail the need for customised products, and also the need to create prototypes for products that may be mass-produced in the end, both of which may be achieved through 3D printing.

Made in China 2025 also encourages IP accumulation, in particular through patent applications and the creation of well-known brands (Li 2017). For 3D printing, China seems to be on course to achieving this goal. According to WIPO (2015) it is the only middle-income country coming close to advanced industrialised nations as regards its number of patent filings in the 3D printing space, many of which have been filed by public institutions such as universities.

Nevertheless, similarly to 3D printing in developed countries, there are various barriers to uptake in China and challenges to be overcome, particularly around the cost of production, and expediency as compared to traditional techniques when a large quantity of a product is required (Chan et al 2017).

2.2 France

2.2.1 Culture: Bricolage

The culture related to 3D printing in France is still not 'mainstream', though the awareness of the technology has certainly grown over the past few years. Several TV documentaries have been shown during prime time on major TV channels (TF1, France Television, ARTE)[1] and were watched by very large audiences. Furthermore, events related to 3D printing (e.g. new technological achievements, adoption by startups or large companies) are regularly covered in the news, whether in the press media or on TV (Fig. 5). While there was a peak of 'popularity' in spring 2014, 3D printing is still regularly featured in the news with a rather increasing trend since 2017. Alongside what happens in the news, the popularity of 3D printing in France started to be noticeable in late 2012 before reaching a peak in March 2014 (Fig. 6). Since then, web searches in France related to 3D printing have nonetheless been increasing with the exception of a further trough in the graph related to seasonality (corresponding with the summer).

Figure 5. News mentioning 3D Printing in France.

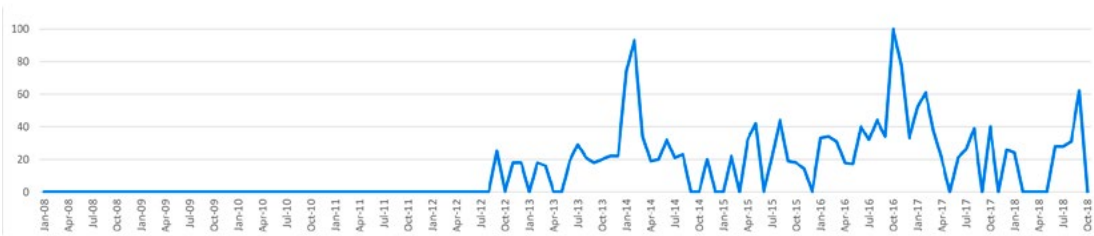
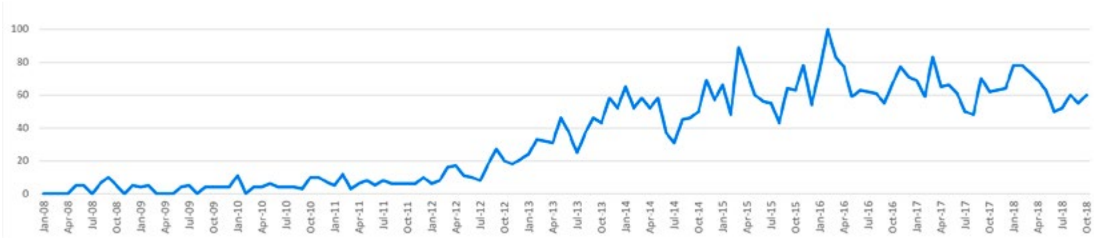


Figure 6. Web searches related to 3D printing in France.

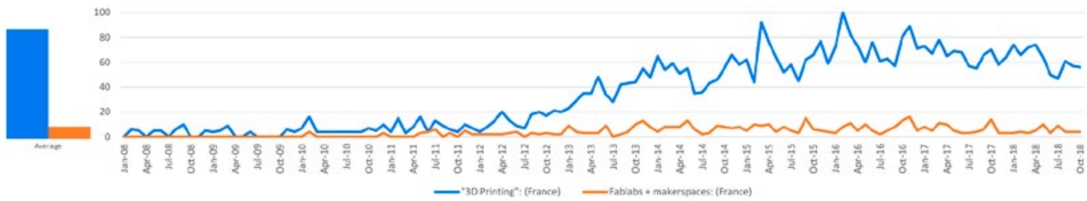


Likewise, there is a growing awareness in France related to FabLabs and makerspaces (Fig. 7).

1 For instance: 'Envoyé Spécial', France 2, 6 March 2014; 'Imprimante 3D, le futur est en marche ?', ARTE, 14 October 2017.

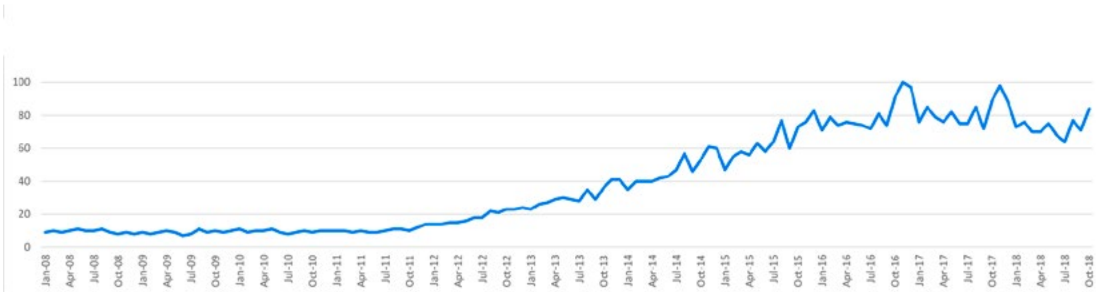
Beside the question of the culture in France related to 3D printing, other cultural elements are of importance for the MLP analysis. Firstly, France has a rather prevalent piracy culture. While pirated products are generally not available ‘offline’ or for sale, French consumers are generally inclined to share digital content with others. Usage of P2P exchange networks, such as Napster, Kazaa or BitTorrent, has been known to be prevalent, but this may well be just the tip of the iceberg, as it is suspected that a large amount of direct copying between consumers also takes place. While attempts have been made to curb piracy in France by means of law (see section 2.2.2), the resulting (arguable) decrease in the prevalence of piracy in France over the past few years is more likely to have been caused by a shift to different forms of piracy (e.g. use of pirate streaming websites instead of peer-to-peer, use of YouTube ‘rippers’) or by the advent of better legal offerings (e.g. Netflix, Spotify), rather than because of a radical shift in culture that would have made piracy less desirable.

Figure 7 - Searches related to 3D printing (blue) and FabLabs and makerspaces (red) in France.



In regard to 3D printing, another driving cultural factor may be the popularity of DIY in France. While French people have always been rather keen on ‘bricolage’, the concept of DIY (which has now become an Anglicism in the French language) has become increasingly popular since 2012 (Fig. 8), and, interestingly, has followed a rather similar trend as 3D printing and FabLabs in regard to public awareness.

Figure 8 - Searches in France related to DIY.



This increasing popularity in France of DIY as a concept has occurred in parallel with a growing dislike of ‘planned obsolescence’, to such an extent that a law was voted by the French Parliament (see section 2.2.2).

2.2.2 Policy: Anti-Piracy

While it is a popular belief in France that 3D printing was invented there in 1984,[2] policy-wise, little has happened until fairly recently. For instance, when in 2015 the French Government launched an ambitious set of 34 industrial plans for industry renewal in France, 3D printing (or additive manufacturing) is only mentioned in passing in the hundred-page-long document. Since then, however, French policymakers' awareness of 3D printing's importance has grown, as evidenced by several reports recently commissioned by the French Government.[3] Over the past couple of years, Bpifrance (the French public bank tasked with supporting innovation) has funded some large-scale projects related to 3D printing—for instance the €50 million SOFIA innovation project led by Michelin and Fives and involving companies such as Safran and Zodiac. The French government has also been highly instrumental in the launch of the Industry of the Future Association (AIF) in 2015 with the aim to structure better the French industry sectors involved in 3D printing, as well as foster the adoption of this technology.[4] Thus in comparison to other G7 countries (such as the US, UK or Germany), France is mildly proactive in its support for the development and deployment of 3D printing. Nonetheless, the current Government, as well as its two predecessors, has set out as an objective the re-industrialisation of France and to boost 'made in France'. While this does not directly relate to 3D printing, this political objective certainly is a supporting factor for the development of 3D printing in France.

As noted in section 2.2.1, there are other elements of French policy that are relevant to the MLP analysis. Strongly pressured by rightsholders, the French Parliament voted a 'three-strike' policy (similar to what was envisaged originally in the Digital Economy Act), named HADOPI, in 2009 (Rayna and Barbier 2010). This law granted rightsholders rights to ensure that consumers' Internet connections were monitored to detect IP infringements (chiefly on BitTorrent peer-to-peer networks). Infringers were sent a first warning and, after a second warning, could receive a fine of up to €1500 and get their Internet connection suspended if caught a third time—although the suspension of Internet connection was abandoned in 2013.

While over 10 million warnings were sent since 2009, only 101 infringers eventually received a fine. Although Government sponsored reports claimed that the policy was effective, academic research has cast a doubt on this claim, noting that piracy displacement was likely to have occurred towards illegal streaming (Arnold et al 2014).

The French 'piracy culture' might be related to another aspect of French IP policy. Indeed, unlike in other countries, in France, people have a 'right to a private copy', which allows individuals to copy copyrighted material – including material they do not own, and so is different from a right to back-up – for their private/family use. In exchange, a tax is levied on devices (e.g. MP3 players, smartphones, tablets) and media (e.g. audio/video tape, blank CDs and DVDs, hard drives) to compensate rightsholders for the loss incurred.

In 2015, some members of the French Parliament put forward a proposition to extend the tax on 'copy devices' and 'blank media' to 3D printers and related consumables.[5] However, this proposition was not adopted, notably because copyright only partially covers the copy of physical objects.

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2 See for instance **http://www.primante3d.com/inventeur/**

3 See for instance **https://www.entreprises.gouv.fr/etudes-et-statistiques/futur-fabrication-additive-pipame** and **https://www.entreprises.gouv.fr/politique-et-enjeux/etude-technologies-cles-2020?tech=9**

4 **http://www.industrie-dufutur.org/aif/**

5 **http://www.senat.fr/seances/s201504/s20150417/s20150417022.html#section3685**

Finally, as noted in section 2.2.1, by popular request, a law banning planned obsolescence was adopted by the French Parliament in 2015. This law forbids companies from artificially reducing the durability of a product to increase the repurchase rate. While this does not necessarily have a direct impact on 3D printing, some companies have, as a result, started to make digital blueprints of parts available to consumers, so that they can extend the life of products. For instance, in 2016, Boulanger, one of the major French appliance retailers, launched an online platform enabling end users to download and 3D print spare parts for appliances.[6] This law also means that it is going to be much more difficult for companies to prevent digital blueprint of parts of their products to being widely made available for consumers to print, which may result in a key driver for 3D printing adoption.

2.2.3 Industry: After the Auto

France is clearly not a major player in the 3D printing industry. The country is, instead, a rather late bloomer. At the moment, only one French company, Prodways, stands out as a major industry player for industrial grade 3D printers (for metal, plastics and ceramics).[7] However, other French companies are gearing up to make up for lost time. Michelin, the leading tire manufacturer and long-time 3D printing user, teamed up with Fives to form a joint venture named AddUp to manufacture metal (laser sintering and electron beam melting) integrated solutions for 3D printing.[8] Recently, AddUp purchased BeAM, a French startup that has developed a metal DED (Direct Energy Deposition) technology. Some French companies, such as 3Dceram (ceramics) and Erasteel (metal) also focus on materials for 3D printing.

Around 2013-14, there was a surge in the number of French startups aiming to commercialise entry and medium-level 3D printers based on Fused Filament Fabrication technology – also known as Fused Deposition Modelling (FDM) – often inspired by the RepRap project. A few of these companies have survived to this day and have been moderately successful: E-Motion Tech, Tobeca, DooD.

Service-wise, there are many 3D printing print-on-demand services in France, generally equipped with machines produced by EOS, Stratasys, 3D Systems, Arcam, and Concept Laser. Furthermore, France is the birth country of Sculpteo, one of the largest online 3D printing platforms, alongside Shapeways and Materialise (Rayna et al 2015).

Finally, though France might not be a leader in regard to 3D printing manufacturers, the country has a significant number or lead-user companies that make an intensive use of 3D printing for prototyping, tooling, or production, including Airbus Group, Ariane Group, PSA (Peugeot and Citroen), MBDA, Renault, Safran, and Total.

A recent study has shown that jobs related to 3D printing increased by 100% in 2017, with a growth rate of nearly 12% per month over the past 24 months.[9]

6 **https://www.happy3d.fr/fr/**
7 **http://www.prodways-group.com/**
8 **https://www.addupsolutions.com/**
9 **http://www.primante3d.com/impression-3d-emploi-22032018/**

2.2.4 Science: Research Excellence

As mentioned in Section 2.2.2, research on 3D printing in France dates back from the early 1980s. However, there were no significant developments until rather recently. Yet, some of the key actors are spin-offs from academic research centres; for instance, BeAM is a spin-off of IREPA Laser, a regional innovation and technology transfer institute. At present, there are numerous research centres in the country specifically devoted to 3D printing-related research.

Furthermore, France has a strong and long-established tradition of research in engineering and hard sciences, which is supportive of 3D printing – for instance, research on lasers, alloys, polymers can benefit directly 3D printing technologies.

2.2.5 Markets and User Preferences: DIY

According to the last Wohlers report, France accounts for only 3% of 3D printers in the world (against 40% for the US), which, in comparison to the size of the country's economy is relatively small. According to the 3D Hubs Q3 2018 report, only 2.5% of the prints ordered through the platform originated from France, against 38.1% from the US, 15.7% from the UK, 6.7% from the Netherlands and 6.3% from Germany, France being ranked 8th worldwide.

There are not precise figures available about the French 3D printing market. Yet, it is safe to say that the industrial usage of 3D printing technologies—whether for prototyping, tooling, or production—is on the rise. As regards consumer markets, all major electronics/appliances retailers in France (Boulanger, Darty, FNAC, Amazon) now sell 3D printing equipment and materials. However, it is hard to estimate the resulting sales. Indeed, along with the peak of interest in 3D printing (mentioned in section 2.2.1) in 2014, a surge in 3D printer purchases was mentioned in the news. Nevertheless, numerous reports of disappointed customers also arose at the time; 3D printing is not yet 'plug-and-play', printing is slow and can be unreliable, and in many cases it is currently difficult to find a practical purpose for it at home.

Nonetheless, as mentioned above, there is a growing awareness in France of sustainability issues, and a stronger taste for DIY, as well, to some extent, for products 'made in France'. Beside the related issues mentioned above, this has also led major DIY store chains, such as Leroy Merlin, to start selling 3D printers and related materials, and also to open labs and 'tech shops' where consumers can receive training. In this respect, it is to be noted that there are currently 110 FabLabs in France, and many more makerspaces equipped with 3D printers.

2.2.6 Technology: Status Quo

With regard to technology, there is nothing particularly specific about France. The current limitations of 3D printing technologies in general (mainly in relation to speed, reliability and cost) do certainly impede a faster deployment of 3D printing in the country. As these improve, additional niches become worthwhile, but nothing so far that would lead 3D printing to become a mainstream manufacturing technology in France.

2.3 India

2.3.1 Culture: Swadeshi

Swadeshi has its roots in the counter-culture of satyagraha in the mid-20th century following the Second World War where opposition to British rule culminated in a nation-wide protest movement led by Mahatma Gandhi. Swadeshi was a form of nonviolent resistance through the mass adoption of 'home-grown/made/spun goods in order to provoke systemic change' (Birtchnell 2012). By revitalising traditional practices such as household cotton-spinning wheels and the wearing of simple cotton clothes (khadi) Gandhi incited a 'nation of weavers'. Gandhi and his followers sought to undermine the British importation and exportation regulations and overall trade hegemony through notions of self-sufficiency, modesty and frugality. In the 21st century swadeshi remains an important culture in nationalist discourses, particularly against global consumption icons such as Coca-Cola (Varman and Belk 2009).

2.3.2 Policy: Digital India

'Digital India' is a programme of policy initiatives by the Narendra Modi government worth US$480 million (INR 3,073 Cr) in 2018-2019. Notable aspects are the Pradhan Mantri Gramin Digital Saksharta Abhiyan (PMGDisha) being executed with an outlay of Rs. 2,351.38 crore to make 60 million rural households digitally literate by March 2019. An incentive in this policy push is the 2016 demonetisation of 85 per cent of the circulating currency that forced citizens to enlist into a digital biodata system called Aadhaar, authenticated by finger prints and retina scans, and India Stack, a series of secured and connected systems for storing and sharing personal data including medical, bank, employment, and residential details.

2.3.3 Industry: Make in India

'Make in India' is an effort to promote national businesses and products through protectionist strategies and the formation of ICT, services and manufacturing clusters involving infrastructure, residential and educational investments. Popular examples of ICT clusters include Bangalore and Hyderabad, which became centres for outsourcing services (Grondeau 2007). The Make in India campaign adopts tariff interventions to promote Indian products. Agrarian transformation will also create a market for Indian technological innovations for farm productivity. The campaign also envisages funding for engineering and technical tertiary institutions.

2.3.4 Science: IITs

India is a world leader in science, technology, engineering and mathematics subjects (STEMs) with its elite Indian Institutes of Technology (IITs) graduating tens of thousands of experts each year. In the late 20th century the majority of graduates from the IITs would work overseas, part of the so-called 'brain drain' (Birtchnell 2013). Partly due to the Make in India campaign, graduates are now electing to stay in India, attracted to the growing ICT clusters and multi-national joint ventures between India and overseas countries. Despite ranking only 44th globally in the 2018 Global IP Index (Ghosh 2018) a facet of the sheer scale of alumni talent is the number of patents filed by Indian inventors in global multinationals, India aspires to be a leader in IP generation. Expertise is a core component of this vision and there is evidence that retention of talent would increase the country's rank. For instance, Indian inventors contributed 658 patents to IBM to help global software giant top the list for US patent recipients in 2016 (BGR India 2017). Notwithstanding its present ranking the number of patents published in India each year is growing as talent remains (Das 2017).

2.3.5 Markets & User Preferences: Middle Class

India's rising middle class is a well-documented surge in the general capacity of India's population to become consumers participating in the global economy for goods and services (Brosius 2010). Centred in major metropolises, notably megacities New Delhi and Mumbai — to a lesser extent in Bangalore, Hyderabad, Chennai and Pune — the middle class are imagined to grow to possibly a billion consumers once the 'bottom of the pyramid' is brought online into global consumer markets (Prahalad 2010). A strategy for encouraging this middle class to consume is the notion of 'frugal innovation' (Prabhu 2017) or jugaad (Birtchnell 2011) wherein products are tailored to expectations and cultures of parsimony in order to balance cost with quality.

2.3.6 Technology: Joint Ventures

Over the late 20th century India's government encouraged joint ventures involving technology transfer between Indian companies and overseas ones. India's history of autarky since Independence in 1947 was understood in the late 20th century as deleterious to its economic growth, investment productivity and fiscal and trade deficits (Auty 1993). Leading up to the 1990s the Indian government undertook tie-ups with overseas corporations through linking its own state-driven companies to multinationals which were incorporated in India and treated to all intents and purposes as domestic companies. The automobile, defence and aerospace sectors led the way with companies including Bajaj (with Kawasaki), Hindustan Motors (General Motors, Mitsubishi) and Mahindra and Mahindra (Ford, Renault) all undertaking notables joint ventures with companies from Japan and Europe throughout the 1980s-2000s.

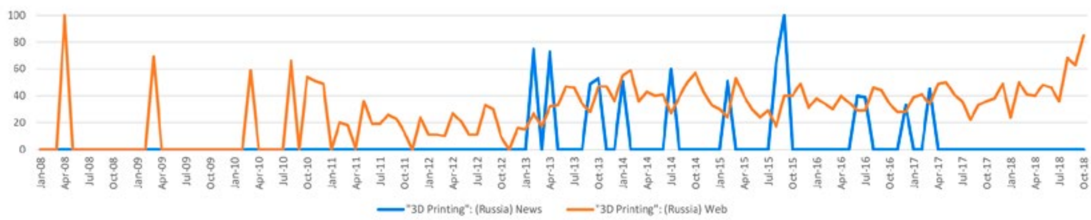
2.4 Russia

2.4.1 Culture: Counterfeit in Decline

Awareness of 3D printers in Russia could be traced back to around 2011, when the first open source 3D printers started to be brought from China. As seen from Fig. 9 there was a pick up in interest in 2013 when news about the first 3D printed gun was announced; since then the interest in the technology has been going up and down, but a clear overall upward trend is visible.

The positive trend could be explained by regular events related to 3D printing, such as Geek Picnic and 3D Expo. Geek Picnic is a festival devoted to science and technology which has been run in Moscow and St Petersburg since 2011. About 30,000 people attend the event in each city to participate in activities which include lectures from scientists like Richard Dawkins and Lawrence Maxwell Krauss. 3D Expo, which hosts around 100 exhibitors each year, has been organised annually since 2014. Finally, the announcement of the installation of a 3D printer at the International Space Station attracted an additional wave of interest in 3D printing.

Figure 9 - News mentioning 3D Printing in Russia.



Another important cultural aspect is related to music and video piracy. Back in the 1990s and early 2000s piracy was a widespread phenomenon in Russia. Counterfeit audio and video tapes could be found easily at stores and markets all around the country, with only a handful of shops selling licensed items. At Gorbushka ('Culture House' owned by the Khrunichev State Research and Production Space Centre), in addition to counterfeit goods, master copies and holograms, as well as equipment to wrap tapes and disks could be purchased. In 1996 Gorbushka was even listed in the Guinness Book of Records in the 'fastest piracy' category. When Microsoft Office 97 sales started in 1996 (US$495 per copy), a pirated version was available at Gorbushka for less than US$5 four hours later.

The situation is quite different today. Not only are counterfeit music and videos nearly not available for sale, the current fashion is to buy and to own original products, rather than counterfeits. This trend is strong, despite the fact that not everyone can afford original products. In 2017, for example 6 million smartphones (26% of those purchased overall) were bought with a loan.[10]

2.4.2 Policy: Factories of the Future

The current innovation plan (2011-2020), developed by the Russian Ministry of Economic Development, is aimed at developing innovation competences, increasing innovation among businesses, developing R&D, developing innovation infrastructure and revising legal provisions to protect better Russian innovations.

The programme consists of three stages:

- 2017-19: Identifying R&D directions to create competences needed in the future.
- 2020-25: Testing technological solutions which will allow Russian companies to become more competitive in the future; the creation of (smart, virtual) Factories of the Future.
- 2026-35: Creating a network of Factories of the Future.

A particular focus of the programme is on developing competences in the area of digital design, new materials, additive manufacturing, robots, big data and Industry 4.0.

During the first stage (2011-13), actions needed to meet the objectives of the programme were identified. Among these was an innovation roadmap developed by the Russian Ministry of Industry and Commerce for 2017-19, which has a section devoted to additive manufacturing. The roadmap is aimed at developing key competences needed to adopt

10 **https://hi-tech.mail.ru/news/6-mln-smartfonov-v-kredit-rossiyane-gonyatsya-za-iphone-i-krasivoj-zhiznyu/**

advanced technologies and to develop necessary business models. The ultimate goal of the programme is to create ‘Factories of the Future’ and eventually to increase Russia’s positioning in the Global Manufacturing Competitiveness Index.

2.4.3 Industry: Home Players

In Russia industrial 3D printers printed started to be used in the late 1980s in airspace and space industries (e.g. Sukhoy Construction Bureau). Today, according to the Russian Ministry of Industry and Commerce,[11] the industrial use of 3D printers is rather limited, mostly for the purpose of rapid prototyping.

As for consumer printers, the first printers appeared in Russia in the mid-2000s, when the first consumer open source printers were brought from China. The number of printers increased around 2012 (when most major FDM printers expired), once again mostly due to the arrival of Chinese printers. It was also in 2012 that the first official dealers opened in Russia and it became easier to buy spare parts.

In addition to players such as Ultimaker and MakerBot there are several Russian companies active in the consumer 3D printing market. One of these is PICASO 3D, a Russian company founded in 2011. According to 3Dtoday, their sales are about 600-700 hundred printers per year.[12] Two other players, 3Dqualit and Magnum have a similar number of sales. Finally, Imprinter sells about 100-150 printers per year.

Among these four players, Magnum is the only company, whose 3D printers are 100% manufactured in Russia. Around 20-25% of other companies’ parts are made in China.

In addition to hardware development, there are also several Russian content providers. At the moment the number of designs on these platforms range between several hundred and 11,000 designs (whereas, for example, Shapeways manufactures and sends out more than 6000 objects every day).

2.4.4 Science: CMIT initiative

As in many other countries (particularly in more economically advanced ones), there has been a sharp decline in interest in engineering in Russia. This decline is particularly striking, as between 1960 and 1990 45% of students (over a million per year) studied engineering.[13]

In contrast, by 2008 the proportion of Russian students choosing an engineering degree had dropped to 18% and has remained at the same level ever since. Similarly, the number of subscriptions to ‘Unnyj Technik’ (‘Young Engineer’) journal has dropped from 1,884,500 in 1981 to just 8,900 in 2018.[14] Furthermore, nowadays, only 5.8% out of the 63% of Russian children attending after-school clubs do activities related to technology and engineering.[15]

11 http://www.nti2035.ru/docs/ДК%20Технет%20%20приложение%20к%20протоколу%20заседания%20президиума%20Совета.pdf
12 http://3dtoday.ru/blogs/sergey/russian-3d-printers-statistics-and-figures-from-leading-manufacturers/
13 http://www.socioprognoz.ru/files/File/publ/Inkzenerno_technicheckoe.pdf
14 http://www.prosmi.ru/catalog/2186
15 https://ria.ru/society/20150316/1052833237.html

In order to tackle such a sharp decline in interest in engineering, the Russian Science and Technology Development Fund for SMEs (STDFS) decided to fund the creation of youth FabLabs across the country. Overall, 240 such FabLabs or ‘Centres for Market Innovation and Technology’ (CMITs) were created.

According to the Moscow Agency of Innovations, the aims of CMITs are to create favourable conditions for: the usage of digital manufacturing; the development of new competencies related to entrepreneurship and engineering; and assistance to those studying engineering in testing, as well as commercialising their innovative ideas by providing them with digital manufacturing equipment.[16]

Though the programme was only launched in 2013, there has already been a positive impact via providing young people with skills and competences needed for digital manufacturing (Rayna and Striukova 2018). In addition to educating young people, CMITs also run programmes for school teachers, who then pass digital manufacturing skills onto their students.

2.4.5 Markets and User Preferences: FabLabs

Currently, the adoption of 3D printers in Russia has not ‘crossed the chasm’ (Moore 1991). At the moment all the ‘enthusiasts’ have already obtained a printer, while ‘pragmatists’ are not yet convinced. In addition to general barriers for adoption such as difficulty of usage, lack of content, and lack of purpose, the adoption of 3D printers in Russia has been also affected by the relatively low mean salary and the increase in other types of living expenses. For example, though the mean Russian salary increased in 2018 by 12% and reached 39,800 rubles per month (£464), health and education expenses during the same period have increased by 63% and 36% respectively.[17] As a simple printer costs about 20,000 roubles (£230) and a Picaso printer 120,000 roubles (£1380), this technology is yet not affordable for many Russian families.

On the other hand, the number of publicly available printers, for example at CMITS, schools and universities, mean that overall there are more and more people who have access to this technology without having to purchase it themselves.

2.4.6 Technology: Early years

Currently, there are a number of companies carrying out 3D printing R&D in Russia. Among them is a company called LAR Technologies, which has recently created a cheap metal printer. Whereas printers from leading manufacturers e.g. 3D Systems can cost about 100M rubles (£1.1M), something not affordable for a lot of companies, the cost of the new metal printer is only 9.8M roubles (£113K).[18]

There is also research being conducted in the area of bioprinting. For example, in 2013 biofabricators of spheroids was invented by Rezende et al (2013), followed by the creation of the first bioprinter in 2014. Currently there is no clear legislation regarding bioprinting, so the printer has not yet been commercialised.

16 http://innoagency.ru/ru/application/support/cmit-support
17 https://www.bbc.com/russian/news-43490885
18 https://promdevelop.ru/news/pervyj-3d-printer-po-metallu-rossijskogo-proizvodstva/

Several R&D units are also engaged in research related to materials, such as composites, polymers, nanomaterials, nanoelectronics and powder. There is also work being conducted to standardise 3D printing materials.

Overall, in the past 15 years, 131 patents were issued in Russia related to additive manufacturing (0.14% of global patents). Only 14 of these patents were granted to Russian inventors.[19]

2.5 Singapore

2.5.1 Culture: Ageing Tiger

Singapore is a highly developed economy situated in South East Asia. Like most developed economies throughout the world, it is facing socio-economic challenges including an ageing population. This is influencing the kinds of innovation being promoted and funded in Singapore, which is strongly biased towards the medical sphere. This may also accord with a 'cautionary' or conservative approach to new technologies such as 3D printing. Singapore was viewed as being 'behind' other developed economies both in the West, and East Asia, in its take-up and implementation of 3D printing so far. Furthermore, despite Singapore's large investment in medical technologies including 3D printing, it was feared that medical practitioners – and patients – would display caution towards new technologies and may need to be persuaded to use and trust them, forming a barrier to take-up and implementation. However, the ageing population in Singapore is stimulating specific kinds of 3D printing research, such as in printing hospital food for elderly patients who may have problems swallowing and digesting normal meals.

2.5.2 Policy: Smart Nation

Singapore's Government has played a strong role in developing policies and other forms of intervention to encourage and facilitate innovation in Singapore (Wang 2018). Singapore currently ranks 5th in the 2018 Global Innovation Index. Singapore's Government aims for the city-state to become the world's first 'Smart Nation' and has a policy to promote this aim among different stakeholders in the public and private sectors, and among ordinary citizens, through the encouragement and take-up of a range of different digital technologies in the Singaporean society and economy.

Innovative manufacturing has also benefitted from Singapore's Government policies, notably the Future of Manufacturing Scheme launched in 2013, one of whose initiatives is the National Additive Manufacturing Innovation Cluster (EDB 2017). Among the sectors targeted in this policy are aerospace and biomedicine. The aim of this policy is to make Singapore a world leader in 3D printing.

2.5.3 Industry: Value added entrepot

The 3D printing industry in Singapore is currently oriented towards high-end industrial applications, in medicine and aerospace for example, as mentioned above, as well as the construction industry. Software for 3D printing is also being developed in Singapore. 3D printing is viewed as a complementary technology to other ones, including other manufacturing techniques, and also as complementary to automation. This orientation to

19 **http://www.nti2035.ru/docs/ДК%20Технет%20%20приложение%20к%20протоколу%20заседания%20президиума%20Совета.pdf**

high-end manufacturing in Singapore is not unique to 3D printing, Indeed, in other sectors, high-end manufacturing occurs in Singapore while its neighbouring countries, Malaysia and Indonesia, provide additional, lower value manufacturing capacity. This can be seen as an extension of Singapore's traditional entrepot economy, involving Singapore importing raw materials, refining them, and then re-exporting the finished products While Singapore also has to import many raw materials for its high-end production, it is viewed as a regional supply chain hub for high value products. While there are some consumer-oriented 3D printing businesses in Singapore and makerspaces, Singapore is the location for a particularly spectacular failure of a 3D printing startup. The provocatively titled Pirate3D was a Singapore startup which aimed to design and sell a cheap 3D printer called 'The Buccaneer'. Crowdfunding was sought through a Kickstarter campaign, which raised more than US$1 million for the project, and garnered significant media coverage. Pirate3D did manage to ship some machines in 2013-2014, but was significantly behind schedule, and eventually offered people who had invested in the project their money back, or to wait longer for delivery of the machine, before ceasing altogether to offer refunds. The company no longer appears to be active.

2.5.4 Science – STEM Focus

Singapore has been highly focused on STEM education and research and development. It is well-known for its excellent education system, and the Government has invested greatly in STEM research and development. In R&D Singapore has adopted conventional approaches to IP accumulation and use, and in this way is aligned with other mature economies internationally.

Specifically, for 3D printing, our participants viewed that IP issues have not been a major concern for Singapore-based organisations. But IP is gaining importance: Singaporean organisations are filing patents relating to 3D printing in Singapore and in foreign jurisdictions; and Singaporean organisations are analysing developments in digital supply chains and preparing for possible IP-related tensions. The Intellectual Property Office of Singapore (IPOS) conducted a review into its registered designs legislation, and considered among other topics whether there was a need to amend the law given the emergence of 3D printing. In its Final Report (2016) it considered that amendments were not necessary at that point in time, but that 3D printing's progress and implementation should be monitored to see whether revisions may be necessary in the future.

In any event, given the strong representation of 3D printing in the medical sector in Singapore, it is sector-specific regulation of the medical ecosystem which may be more of a barrier or challenge to the take-up and implementation of 3D printing, along with cautious attitudes towards the adoption of new technologies from doctors and patients as mentioned above.

2.5.5 Markets and User Preferences: Offshore mass production now, local 3D printing later?

3D printing at the consumer level does not seem to have taken off in Singapore, and the uses of 3D printing in high-end industries seems much more prevalent. The failure of consumer oriented local startup Pirate3D reinforces this view that consumer 3D printing is not the primary implementation of the technology in Singapore. The fact that Singapore is a rich economy and very well connected to global supply chains may partially account for this scenario. Indeed, the Singaporean participants referenced developments in China on more than one occasion including the mass production of cheap goods there which are then sold in Singapore and elsewhere.

However, China's current perceived capacity to (mass) produce cheap items, coupled with Internet platforms such as Alibaba to facilitate transactions was viewed by the Singaporeans as a temporary state of affairs that would 'fade away' with better 3D – and 4D – printing technologies. In this future scenario, better and easier-to-use 3D printing would facilitate localised production of goods for the Singaporean market.

2.5.6 Technology: Convergence and Climate

In Singapore, convergence among new emerging technologies, and the challenges posed by climate change are driving technological investment and development in the city-state. Participants specifically pointed to automation in the hospital context as converging already with 3D printing to address challenges presented there by the ageing population. As mentioned above, 3D printing food in hospitals was already being investigated. Furthermore, participants pointed to the challenges of climate change and exhaustion of natural resources in the future as factors which may encourage further 3D printing of food, and also circular economy practices around waste.

2.6 United Kingdom

2.6.1 Culture: Great Again

After many decades at the forefront of globalised neoliberalism, continued in New Labour's 'third way' reforms, the UK may be viewed as entering a period of cultural introversion since its decision to exit the European Union. A more 'closed' culture to external influences may be currently emerging in the UK. This may stimulate more localisation, including as regards technologies such as 3D printing. However, the UK's departure from the EU may also stimulate new trade partners and routes, and could provide new outlets for goods produced in the UK, including through 3D printing.

2.6.2 Policy: The World as Oyster

The UK's departure from the European Union, scheduled for 2019, may have an impact on all areas of domestic and international policy in the UK. The precise terms of the UK's exit are not clear at the time of writing, including the future relationship with the EU. Nevertheless, it is possible that there will be a strong break from the EU, which may have a significant effect on various areas of policy, including trade, manufacturing and innovation, which in turn will impact upon 3D printing and IP. Whether this impact will be positive or negative is unclear at the current time and dependent on a number of factors. However, boosting domestic production including through technologies such as 3D printing may benefit the UK's future trading relationships with the EU and other countries.

2.6.3 Industry: Onshoring

As a post-industrial nation which has offshored a significant amount of manufacturing to places such as China and which also has a significant number of underemployed workers perceiving a decline in their living standards, onshoring manufacturing back to the UK has emerged as a suggestion for UK industry.

Industrial policy supporting onshoring with a particular focus on 3D printing can be found in the recently released Additive Manufacturing UK National Strategy 2018-25, devised by government-supported independent stakeholder group AM UK (2017). The Strategy aims, like many of the others propagated by governments from Germany to China, to position the UK as a world leader in additive manufacturing. Implicitly Brexit may be an opportunity to do this, although the Strategy acknowledges the uncertainties that currently surround the event.

2.6.4 Science – STEM Boosts

As in other countries, STEM education has been a priority in the UK, in both schools, universities and other educational institutions.

Again, as in other countries, with a poorer-than-expected interest from consumers in 3D printers, many companies have sold machines to educational institutions, which can be viewed as facilitating STEM education. However, there are barriers to students and pupils learning the requisite skills if their teachers and lecturers do not possess these skills themselves, which, our participants viewed, was often the case.

2.6.5 Markets and User Preferences: Small Tech

The Facebook-Cambridge Analytica scandal and other concerns about 'too big' tech companies such as Google has prompted discussions on both sides of the Atlantic and also further afield regarding the power of Big Tech companies and whether the capitalist model of technological development from which these companies have emerged is actually serving social and political goals. One example of these discussions is the recently launched House of Lords inquiry into Internet regulation (2018), although the outcome of this inquiry is unclear at the time of writing.

Concern about the power wielded by large technology players was raised by participants, who envisaged that the future may bring about smaller, more socially-oriented technology companies, including in the 3D printing sphere. This may also have an impact on IP laws and practices, with socio-cultural trends possibly leading to a more open and commons-oriented innovation ensuing from a less capitalist approach to technology.

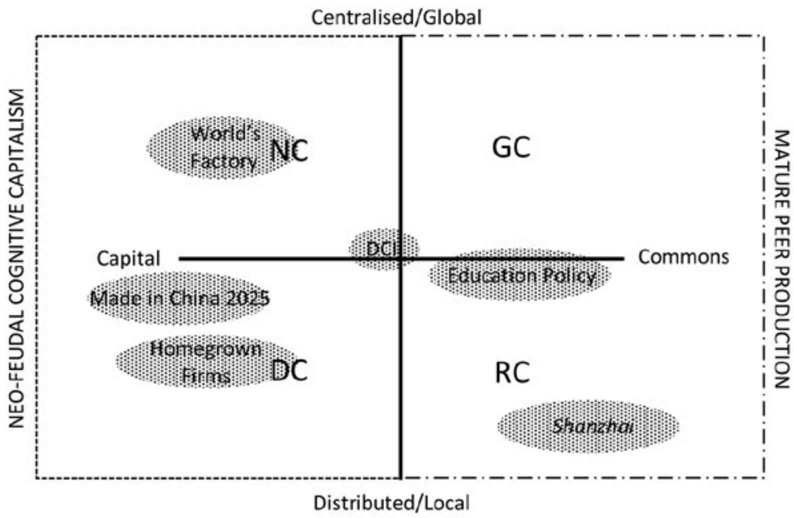
2.6.6 Technology: March of the Makers

In the UK, climate change was also viewed as a factor which may determine the kinds of technologies being created and implemented in the future. This includes 3D printing, which may be used to facilitate, for instance, a more circular economy, minimising waste and in fact utilising waste products as raw materials. Aside from the technologies which may be developed due to climate change, climate change may also drive the UK's political economy away from a capitalist one and to a more socially-beneficial, commons-based model.

3 Foresight and Backcasting

3.1 China

Figure 10 - Two axes and four futures scenarios from the MLP (adapted from Kostakis et al 2016): China.



3.1.1 MLP in Foresight

China is now a more mature industrial power than India for instance, but it is still in transition across many of the MLP dimensions (Fig. 10). This is evidenced by the large number of government policies in this area and a complex attitude and practice towards innovation and IP, which previously has involved copying and sharing (sometimes in less than legitimate ways) as represented by shanzhai practices, but now is beginning to resemble more 'conventional' IP from Western contexts. It seems that digital technologies in China are moving towards a more capitalist model despite China's ostensible communist political regime, which some may feel to be in principle closer to the 'commons'. We project from the workshop data an ideal vision emerging wherein a window of opportunity opens up in China's future for ubiquitous 3D printing across an alternative regime's dimensions in the following way in the short-, medium- and long-term. The distance of each dimension from the select quadrant determines its pathway.

3.1.2 Backcasting Milestones from the NFCC Vision: Global or Local?

The visions of ubiquitous 3D printing most prevalent in the workshop were firmly in the NFCC camps, with participants roughly split in disagreeing on whether the NFCC vision of ubiquitous 3D printing would take a global or local character. Despite China's moves towards more IP accumulation, more open innovation approaches to IP owned by others over software and machines would be an important short-term step towards ubiquitous 3D printing under either vision of 2050, bringing costs down and disseminating the technologies more widely. Yet further commercialisation of 3D printing is a necessary step towards a capitalist ubiquity in 2050, including the utilisation of IP rights, which may be a more medium-term milestone. A more globalised 3D printing industry would require more multicultural understanding and engagement within China and in its relations with other peoples, which would be a medium-term milestone. If this increased multicultural understanding and engagement does not occur, then the 2050 vision of 3D printing in China may be more local, largely contained within this large populous country's own national market.

3.1.3 China 2050: Knowledge Powerhouse

China is moving towards a capitalist innovation paradigm and in many cases instituting policies not so dissimilar from the West. This includes a complex relationship with IP, both currently and in the projected futures. While open innovation/shanzhai approaches are important steps for 3D printing ubiquity, the increase in more conventional (from a Western perspective) IP practices will be key to bringing China to a digital capitalist vision of 3D printing in 2050.

The extent to which China 'opens' to the rest of the world culturally – and its home-grown industry internationalises economically – may determine to what extent this digital capitalism has 'Chinese characteristics' or is a very globalised scenario. China has embraced certain aspects of capitalism since the Deng Xiaoping-led Reform and Opening Up started in 1978. Further opening may be determined by the extent to which China considers it will gain through participation in the global capitalist economy – the more it will gain, the more it will open.

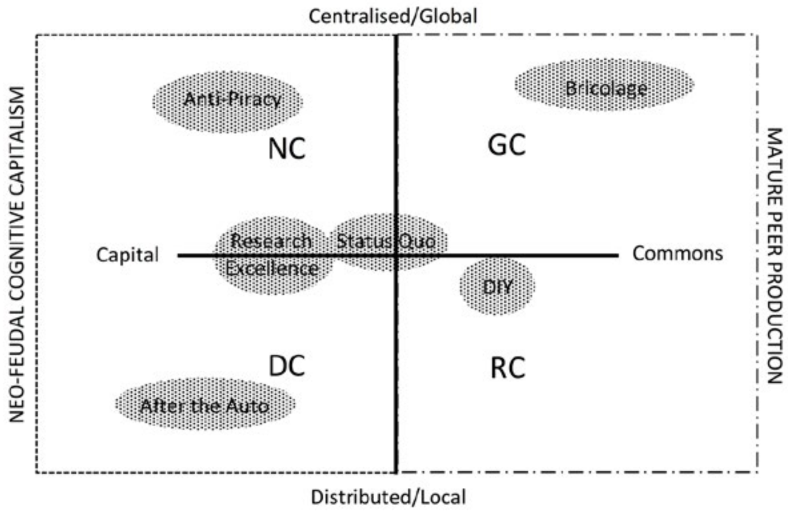
Nevertheless, the two—globalisation and 'Chinese characteristics' — may not be in opposition to each other: Chinese Internet services are currently transnationalising, and the Chinese Government's flagship One Belt One Road initiative also comprises a 'Digital Silk Road' element. It may well be that by 2050 3D printing has both Chinese (capitalist) characteristics and is globalised by exporting these Chinese characteristics internationally.

3.2 France

3.2.1 MLP in Foresight

The Multi-Level Perspective workshop conducted in Paris revealed indeed that in regard to the technological niches, there were very few micro events happening in France before the early 2000s, with a clear rapid growth of such events in France from 2010 onwards. A significant number of events listed by the participants relate to RepRap printers and the launch of startups/printer models inspired by this project in France. The opening of the first FabLabs in France was also noted as an important milestone. Participants also mentioned the important role played by key industry players, such as Michelin or Alstom, in accelerating the adoption of the technology. Many of the events mentioned, though, related to new usage of the technology, of in relation to medical applications (e.g. prosthetics, bioprinting), but also usages related to the use of 3D printing to build houses, manufacture toys, or in art. In regard to IP, key events mentioned were the expiry of the FDM patents in the mid-2000s, as well as the early piracy warning raised by Disney in the mid-2010s.

Figure 11 - Two axes and four futures scenarios from the MLP (adapted from Kostakis et al 2016): France.



3.2.2 Backcasting Milestones from the NFCC Vision: Global or Local?

With regard to the Socio-Technical Regime layer of the MLP, participants noted several important policy drivers specific to France, such as the Industry of the Future governmental plan and the 'reindustrialise France' support policy, but also, more generally, policies aiming to support innovation and entrepreneurship in general (the 'French Tech' of the previous Government, turned into 'startup nation' by the current one). In this respect, the governmental decision to foster greater investment in 3D printing in France, through the public investment bank Bpifrance, was listed as a positive policy driver.

Participants also noted the failed attempt to levy a tax on 3D printers and materials as a key policy aspect. Outside of France, the FDA decision in the US to simplify the approval process for medical devices was seen as an important step forward that could help 3D printing diffusion.

In regard to culture, the most prevalent items related to the 'maker' and FabLab culture. The growing popularity of the circular economy concept, as well as the growing awareness of environmental issues, were also mentioned, from a user preference perspective. As having a potentially positive impact. In regard to science, participants mentioned the importance of the EU Horizon 2020 programme, which supports projects directly and indirectly related to 3D printing. In relation to the industry drivers, the entry of large players, such as GE and Michelin, into the market, as well as mergers and acquisition in the 3D printing sector were the most important aspects mentioned. Finally, in regard to technology, beside improvements of the 3D printing technology itself, participants listed the advent of other technologies, such as AI and virtual/augmented reality as an important driver. One participant noted that the large availability of smartphones meant that basically anyone had 3D scanning capabilities at hand.

Finally, the landscape developments (i.e. the macro global trends influencing the technology adoption) mentioned during the workshops related to environmental issues (climate change), the worldwide issue of refugees (caused by war or climate change), the changing nature of employment (more unstable, with a greater variety of jobs), relocation of small-scale production nationally, and the conquest of space. Interestingly, the ageing population was not mentioned explicitly, though most of the development of the 3D printing mentioned in the foresight exercise related to health and overcoming ageing.

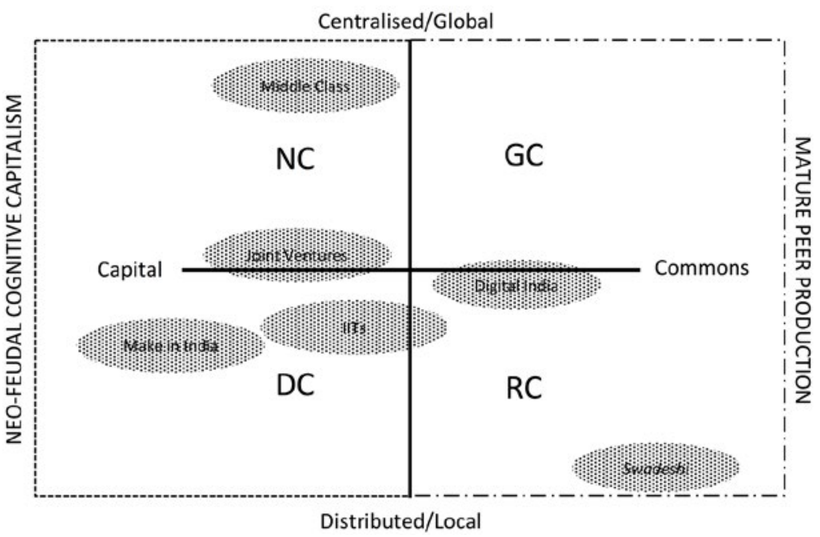
Pushing towards the 2050 horizon, participants saw several types of trends. A first one, as mentioned above, related to the usage of 3D printing in the medical sector, with a growing importance from now to 2050, with in 2050 the ability existing to print all sorts of organs (or even to bioprint directly into the body) and, thereby, to extend human life significantly. Another trend related to the automotive industry, with the ability by 2030 to print a significant amount of parts. Finally, by 2050, several participants mentioned the availability of one 3D printer per home (or at least per building), and the ability of such printers to print many different materials, including food (it is expected by 2050 that all animal proteins can be printed).

3.2.3 France 2050: Connected Individualist

France in 2050 is an ageing country with over half of its population over 60 years old. The key market for 3D printing relates to the health industry, which enables people to live even longer and, therefore become even older. This, in turns, provides strong grounds for customised items – older people are more likely to have individual specific needs – whether in relation to drugs, food, or objects. This, as well as the fact that many inhabitants may be facing mobility issues, provides a fertile ground for a greater availability of 3D printers at home, or at least locally. While the retirement age will most likely have been pushed backwards by then, the large proportion of retired people, as well as the changed nature of employment (more casual/less secure in nature) probably means that a significant part of the population engages in co-creation and shares design. However, despite this local production and community innovation, it is unlikely that, overall, the system becomes completely decentralised, with most likely one or a few major platforms controlling the content sharing – if just for the reason of guaranteeing the safety of what is being 3D printed—older people tend usually to be more risk averse than younger ones.

3.3 India

Figure 12. Two axes and four futures scenarios from the MLP (adapted from Kostakis et al 2016): India.



3.3.1 MLP in Foresight

The efforts in policy towards including the majority of India's population in a digital society necessitates dependence on the global commons, although a prominent feature of this movement is the enlistment of local technology diffusion into the systems of governance (Fig. 12). With the cultural popularity of swadeshi across India's lower socio-economic demographic the propensity to interpret populist motivations in this policy will encourage digital technologies to be distributed and in the commons.

3.3.2 Backcasting Milestones from the 'Resilient Communities' Vision

A short-term milestone will be the alignment of culture and policy towards inclusive digital self-sufficiency creating landscape pressure for employment in the nation's knowledge economy for lower socio-economic demographics and demand for distributed digital fabrication technologies that complement investments in off-grid energy and infrastructure.

A medium-term milestone will be the expansion of the elite IITs into a nationwide network of educational providers that prime graduates for employment in local communities rather than the 'brain drain'. Here training in English language proficiency and skills understood to be desirable for the global economy (e.g., software coding or hospitality) will recede in favour of digital artisanal trades and digital design competence.

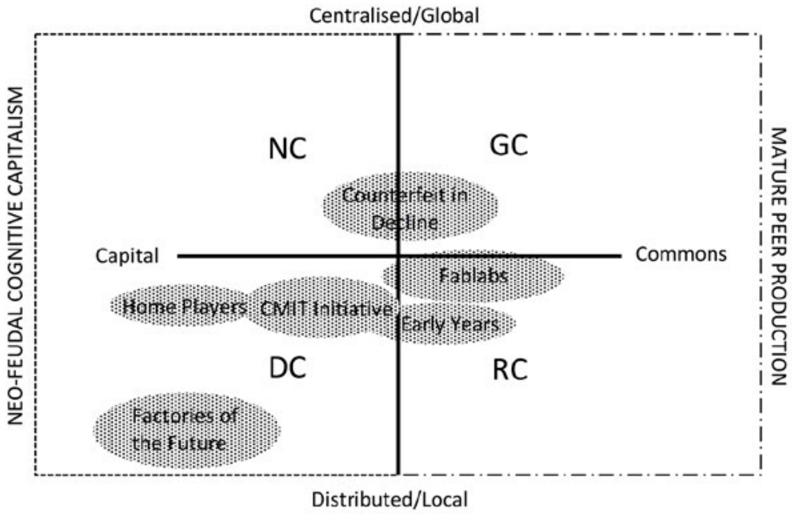
The long-term milestone will be to transform industry to be a major supporter of India's majority population through decentralised networks that involve technology transfer in the commons in the form of support for quality of life and living standards rather than capital accumulation and economic growth. The government will adopt a widespread strategy to encourage 'make in India' through industry support and investment. One method for inciting this nation of digital makers is for joint ventures of industry with non-governmental organisations and charities that privilege technology diffusion for environmental and social justice concerns. Here Mahatma Gandhi's vision of cottage industries would be revamped through a transformation of India's major industrial houses into facilitators of development.

3.3.3 India 2050: Digital Loner

The cultural impulse towards self-sufficiency that led to autarkic but inclusive policies will drive innovation in 3D printing technologies that are made either entirely locally or with overseas partners, drawing on the research talent of India's educational centres and industrial clusters, and the appetite for products amongst India's middle class that combine local concerns (for instance, with customisable religious icons for festivals) with notions of cosmopolitanism and modern convenience. The revanchism of Indian manufacturing and efforts to bring the country's vast rural populations into digital markets will provoke local opportunities for 3D printing that hinge on open access and freely available digital designs that draw on frugal innovation for cost-effectiveness and material resource sustainability.

3.4 Russia

Figure 13 - Two axes and four futures scenarios from the MLP: Russia (adapted from Kostakis et al 2016).



3.4.1 MLP in Foresight

The Multi-Level Perspective workshop conducted in Moscow revealed that most of the micro events related to 3D printing (festivals, expos etc) started to happen in the 2010s. After the initial adoption of the technology both by business and consumers, participants noted that currently there is a period of stagnation (Fig. 13). In particular, participants believed that growth in consumer printing will only happen when the technology has significantly improved. Interestingly, participants believed that this could be done more successfully by the community, rather than by companies. However, it was also mentioned that in order to speed up adoption, large companies need to start investing in 3D printing (e.g. like General Motors in the US or Airbus in France or Deutsche Bahn in Germany).

3.4.2 Foresight: Drivers

Pushing towards the 2050 horizon, participants saw several types of trends.

Similar to France and Singapore, potential greater adoption in sectors such as medicine and dentistry was mentioned. The orthopaedics sector was also mentioned as a possible driver. As for consumers, printing toys was mentioned as a possible driver of consumer 3D printing adoption as they are usually expensive and break easily.

Another possible driver is the potential role 3D printing may play in reshoring or onshoring (i.e. manufacturing in Russia what is currently manufactured in China), especially for goods which are needed urgently, but are currently shipped from China. Indeed, according to the Russian Quality System (Roskachestvo) 91% of Russians prefer buying goods manufactured in Russia.[20]

20 **https://roskachestvo.gov.ru/news/9-iz-10-rossiyan-predpochitayut-otechestvennye-tovary/**

Content is another important driver and according to the participants, policies should be developed to encourage content creation.

Finally, changes in standards could play an important role in adoption. Currently, certifying 3D manufactured products related to medicine (e.g. prosthetics and tools) can take up to 1.5 years, a very long time for someone waiting for a knee replacement for instance, and is also very expensive.

3.4.3 Russia 2050: Platform Pioneer

Workshop participants believed that there are only 2 future scenarios in which 3D printing can present potential risks. One scenario is when nearly everyone has a printer. The second scenario is when nearly everyone participates in co-creation.

Participants were rather sceptical about the first scenario: they suggested that 3D production will remain centralised, as skills and standards are lacking. Also, as many people do not have either the time design or knowledge (and often both), pseudo-customisation platforms are likely to appear, where users will be able to modify some of the parameters of the objects.

In the case where almost everyone will engage in co-creation, it is important for companies to be proactive and to rethink their business models in order to support consumers and to compete with them.

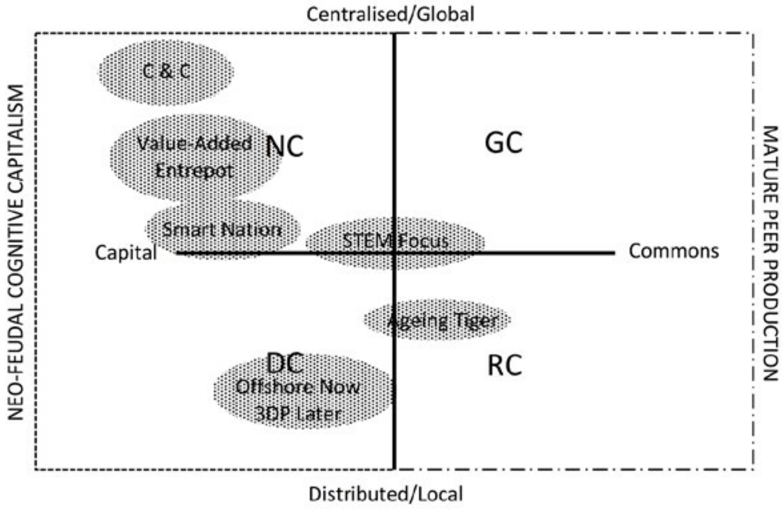
Being ahead of piracy instead of fighting it was identified as a feature: for example, knowing that consumers can print spare parts could be reflected by the original price of the good.

3.5 Singapore

3.5.1 MLP in Foresight

Singapore is a small, mature and affluent economy in South East Asia. It has a tradition of government intervention to stimulate the economy including innovation, a conventional approach to IP accumulation and enforcement and a mature consumer base used to a high standard of living. Singapore is in transition like many similar economies demographically due to its ageing population, and need to find its distinctive place in a world which is becoming increasingly multipolar economically, and in a region where China and India are rising as major global economic powers. Part of this need for distinctiveness can be seen in the Government's policies to make Singapore a leader in 3D printing and other advanced technologies.

Figure 14 - Two axes and four futures scenarios from the MLP (adapted from Kostakis et al 2016): Singapore.



3.5.2 Backcasting Milestones from the NFCC Vision: Global or Local?

Similarly to China, the visions of ubiquitous 3D printing most prevalent in the workshop were firmly in the NFCC camps, again with disagreement as to whether 3D printing in 2050 would take a global or local character. In fact, participants disputed this binary distinction between global and local for capitalist 3D printing in 2050, and viewed that actors in different industries producing different kinds of goods may have a more global, or more local character; or, that there would be aspects of 3D printing which were localised and capitalist, and aspects of 3D printing which would be localised and capitalist.

3.5.3 Singapore 2050: Smart Entrepot

Singapore currently shares many similar characteristics to developed Western economies in terms of level of economic development, consumer preferences and age demographics. Where Singapore differs is its geographical location and very small geographical size. Singapore's geographical location in South East Asia already positions it as a supply chain hub for that region, and its points of distinction with neighbouring countries (such as technological advancement and wealth) may influence the trajectory of 3D printing there to the year 2050. It may well be that Singapore, by concentrating on high-end industries, becomes a specialised digital manufacturing 'entrepot', using raw materials and products from lower-end industries to create highly specialised outputs, which then may be used in Singapore or delivered to recipients in other countries. The investment in 3D printing in the medical industry, also driven by demographics, could be an example of this. A more truly localised scenario in Singapore could involve all production taking place via 3D printing in the city-state, using raw materials which have been locally sourced, and could be driven by climate change necessitating auto-production using e.g. waste in a circular economy fashion (Fig. 14).

3.6 United Kingdom

3.6.1 MLP in Foresight

The United Kingdom is at a particularly unusual point in its trajectory with the issue of Brexit dominating discussions, but also possibly upsetting the status quo in various respects, which emerged in our participants' views of the future scenarios, especially as regards their identification of alternative trajectories to the neoliberal capitalist one the UK has ostensibly been following since the 1980s. At the time of writing, the UK's future trajectory is unclear, and may hinge on events in the near future (Fig. 15).

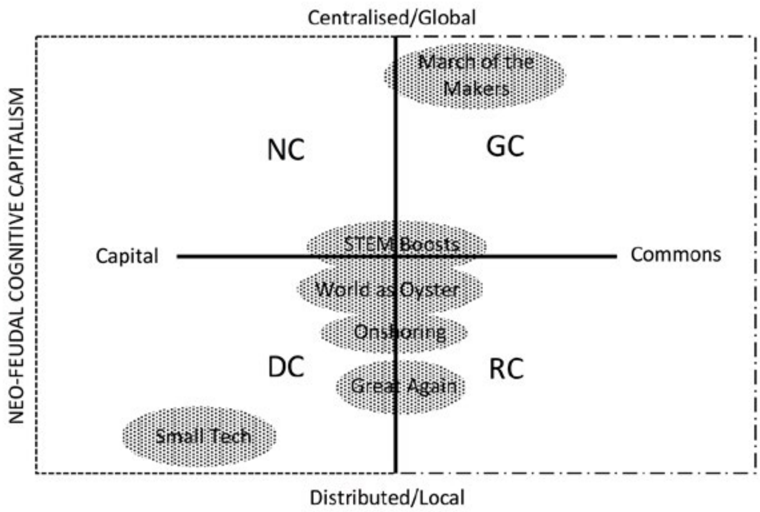
3.6.2 Backcasting Milestones

The UK had a rather different vision of 3D printing compared to other workshops. The vision seemed much more local, with the distinct possibility of a more commons-based future in 2050, given anxieties about globalisation, capitalism, climate and large technology companies identified by participants. Some of these factors could lead to a more local, protectionist but still capitalist vision for 2050. Much depended on how these factors would be addressed in the short to medium-term – would they give rise to a definitive break with capitalism, or only a break with the neoliberal globalised variety of capitalism?

3.6.3 United Kingdom 2050: Local Britain

There are currently some very UK-specific phenomena, beyond those shared by other developed economies that we examined such as Singapore, driving a vision of a much more 'local' - and possibly also much less capitalist – scenario for the UK for 3D printing in 2050. Brexit and its associated factors, as well as scandals involving large technology companies and a perception that (globalised/neoliberal) capitalism may not be 'working' for British people may influence a much more localised picture for 3D printing – and other economic activities in the UK. This may be compounded by climate change and the environmental need for a circular economy, beyond any political needs for this due to less globalised trade and possibly an anti-capitalist, commons-based domestic political economy in the UK. While the UK Government (2018) is currently promoting a 'Global Britain' post-Brexit which images an 'open outward-looking and confident' country, and the specific strategy to make the UK a global leader in 3D printing, our participants viewed a different, more local future for the UK, including as regards 3D printing. The implications for IP may differ depending on what kind of Local Britain is adopted. In a capitalist model IP will still exist, but in a common-based model, that may not be the case by 2050 if it is viewed that the current IP system does not adequately share the benefits of innovation and creativity in a just way among the population.

Figure 15 - Two axes and four futures scenarios from the MLP (adapted from Kostakis et al 2016): UK.



Part III Recommendations and Conclusion

Our horizon scanning workshops gave rise to various findings from which we draw recommendations here.

Main Findings

In the countries we examined, we see a number of similarities regarding 3D printing and/or IP. For instance, most of the countries we examine have—to some extent—government policies to stimulate the creation and take-up of new technologies including 3D printing, such as Make in India. Interestingly, the UK Government is somewhat behind some of the countries (e.g. India and China) in crafting its own policies in this area, but still ahead of others (e.g. France and Russia).

In none of the countries examined does 3D printing appear to be posing fundamental challenges in practice to IP at the current moment in time. This is due to a number of reasons, including a lack of take-up across the board at the consumer level, and more prominent uses of 3D printing in more centralised and/or industrial contexts. Another factor explaining this may be the level of respect for IP rights in the various systems we examined, which also be attributed to e.g. reforms to IP in China and in Russia and changing consumer preferences in recent years.

IP is far from the only area of law involved with 3D printing, and may not be the most important legal concern for those operating in the 3D printing industry. In some cases, product liability, health and safety regulations and sector-specific regulations may be more important hurdles for products and services to get to market rather than IP, and uncertainties around the application of these areas of law to 3D printing may impede the utilisation of 3D printing innovations. Medicine and associated sectors feature strongly here, with participants from Russia and Singapore pointing to specific barriers. In addition, there is ongoing concern about 3D printed firearms from 3D printing industry stakeholders, which is reinforced by recent developments involving the US Government and Defense Distributed's legal settlement which may see gun blueprints more readily available again.

Yet IP is not unimportant for 3D printing. This can be seen from patenting activities, including the accumulation of 3D printing patents by the US and China (see e.g. Rodríguez-Salvador et al 2017). The expiry of patents was also widely pointed to as an important event for the dissemination of 3D printing in many countries. The possibility of more IP litigation was raised by some participants. Although the precise topics for such litigation remain to be seen, especially whether the litigation will concern patents over 3D printing machines and processes, as has generally been the case so far (and in fact seems legally not controversial) or whether this litigation will involve other, more theoretically problematic, aspects of 3D printing and IP identified in the legal literature mentioned in Part II. While academic and practising lawyers have raised various issues regarding the application of IP laws to 3D printing, as identified in the legal literature review above, these issues, and at times the lack of clarity in the law's application, do not seem to be overly affecting the use and take-up of the technology.

Other commonalities can be found in the relationship between 3D printing and other emerging technologies such as automation, IoT, artificial intelligence and blockchain being identified in many places as a cross-fertilisation. That is to say, it is more appropriate to examine and understand the development of 3D printing in the context of the development and implementation of these other technologies, and also to examine the interactions between them. Indeed, as noted in Rayna and Striukova (2015), 3D printing is likely to remain a niche manufacturing technology – of growing importance, but a niche nonetheless – until it becomes combined with other emerging technologies.

Nevertheless, some country-specific issues were also identified. One example can be found in Singapore, where an ageing population is influencing government policy, and in turn influencing the kinds of 3D printing applications gaining investment – in this case, medical uses of 3D printing. Although not (yet) the explicit target of dedicated policies, the ageing population is also a key driver for 3D printing in the medical sector in France.

Furthermore, political/cultural country-specific phenomena, especially in developed economies, which have long since offshored a significant amount of manufacturing and industrial activities, are also influencing the direction of 3D printing's future. Countering this trend, there seems to be leading to renewed interest in re-invigorating manufacturing within the nation-state. The political imaginary of 3D printing here is a technology which can achieve onshoring and fulfil these political promises. To what extent that is realistic remains to be seen, particularly given competition from Asian and other Western economies with their own government stimulation of 3D printing. Indeed, the large number of 3D printing-based prototyping services currently operating in China and targeted at Western companies shows how competitive, regardless of technology, China remains and how much the country is a strong attractor for outsourcing, even in the case of technologies, such as 3D printing, that do not a priori require concentration of manufacturing in either time and space.

The projected future outlooks for 3D printing and IP vary quite significantly among the countries examined. Indeed, the Asian countries, whether developed or emerging, are broadly more aligned with a capitalist future outlook, which would likely implement and preserve 'conventional' IP laws and practices. Likewise, for Russia, the prospect of a move towards significant peer production with a greater role of commons was deemed highly improbable, even in the medium to longer term. The future outlook for the UK and France diverges from this picture by opening more possibilities for commons-based scenarios which may give rise to more challenges to conventional IP, in particular because of a potential significant rise in co-creation, whether sponsored by the firms, or taking place autonomously.[21] Yet, as noted in Rayna and Striukova (2015), potential IP issues—whether of attribution or enforcement—arising because of co-creation, do not necessarily become actual IP issues. Indeed, both types of issues can be alleviated by integrating co-creation within the business model of the firms.

Nevertheless, India remains a possible site for a large manufacturing paradigm change given pre-existing conditions and the promise of 3D printing there. Indeed, Michael (2013) speculates that 'India has the most to gain from the additive manufacturing revolution, while China will lose': due to the possible threat from 3D printing to China's low-cost manufacturing base, and India's current industrial under-development and logistical challenges making it well-placed to implement small-scale 3D printing. So far, though, while 3D printing is present in India, it seems to be less prevalent, with Indian 3D printing so far having less impact on domestic and international commerce than has been the case with China and the West. Yet various commentators (e.g. Singh and Nafis 2015; Arora 2018) consider that there a significant potential for 3D printing in India, which may be realised in the coming years. India also has favourable demographics in the form of a large youth population while China looks to

21 I.e. users modify existing products or create entirely new ones, inspired by a particular brand, such as the Game of Thrones iPhone dock (Rayna and Striukova 2016) without the authorisation of the original producer.

its own demographics ageing in the coming decades. Although India may not replace China as the 'World's Factory' it could be the site of pioneering localised and distributed manufacturing, a model which may be adopted elsewhere especially in other parts of the Global South.

Nevertheless, we do not wish for these findings to be overly generalised or generalising. The actual future for 3D printing may also vary greatly between different sectors even in the same country, where some sectors will experience more bottom-up grassroots co-creation involving 3D printing, and others may see more commercialised and centralised implementations of 3D printing. We may see aspects of common-based and capitalist tendencies co-existing in the same country or same sector, as they do to some extent at the current moment in time. Furthermore, given the experimental nature of much 3D printing research at the moment, for example in the medical and culinary sectors, it will still be important to examine the actual implementation and applications in practice, and thus to cut through new hypes around the technology's possibilities in contrast to the commercial and social realities.

Recommendations

1. 3D printing remains a technology very much in development. Our first recommendation is that various aspects of these developments continue to be monitored. In particular: the extent to which 3D printing is successful in reinvigorating national manufacturing agendas; and the practical opportunities 3D printing offers for localised manufacturing in contrast to the current situation of a 'World Factory', containerisation and cyclic consumerism. We also recommend that factors beyond the purely technological and economic continue to be monitored, especially cultural and political factors. Furthermore, given future outlooks for 3D printing and IP vary between and among countries and sectors, country-to-country and sector-to-sector differences should also be monitored. Prominently, the rise of China, and the potential rise of India into the ranks of developed economies with large middle classes exhibiting a strong showing in innovation, including in 3D printing, should be monitored – and not only the influence of, and developments in, the US and other Western 3D printing ecosystems. Already we see that developments in China present a much more complex picture than the idea that China is only a user, and infringer, of others' IP.
2. We did not find a pressing need for legal reform from representatives of the industries participating in the horizon scanning workshops, including the creative industries, medicine, law, industrial manufacturing and research. Nevertheless, going forward we recommend legal clarification of existing theoretical IP issues exposed by 3D printing and detailed in Part II. These issues include the subsistence of IP rights, identifying activities which constitute infringement especially secondary infringement and how some exceptions to infringement operate. The limited litigation so far on 3D printing internationally has not been on these topics and accordingly has not provided clarification.
3. The European Parliament recently adopted a Resolution on 3D Printing which included the possibility of the EU adopting new laws or modifying existing legislation to address IP and civil liability aspects of 3D printing. The UK should follow the progress of this process, and consider aligning any revisions of its own laws with the outcome of this process.

4. While each new wave of digitisation has its own specificities—and as highlighted in this report, 3D printing certainly does—past episodes of digitisation can nonetheless provide important insights. In this respect, all past waves of digitisation, whether of games, music, films and TV shows, books, show that it is critical to consider business model issues alongside IP issues. In those industries, newcomers (e.g. Spotify, Netflix) have been able to erode the dominance of long-established market leaders simply because they were able to adopt a business model that was better suited to the new 'reality' of the digitised industry. Yet, as noted in Rayna and Striukova (2016), business model innovation is one of the most difficult forms of innovation, as it is highly unpredictable and generally requires forgoing what has made the company successful until then. This is, of course, even more so in the case of a technological change, such as that of 3D printing, where the technological, social and economic evolutions are themselves highly uncertain. One key recommendation is, therefore, that companies and the industry at large should not be left alone with this daunting task. Instead, Government should work with industry to create transition 'champions' which could help companies, as was done in this report, understand the arising technological, economic, social and legal issues and rethink their business models to achieve long-term competitiveness. Since such issues are only going to become prevalent as 3D printing advances and becomes increasingly adopted along with other emerging technologies, this may well become a critical aspect of industrial policy.

Conclusion and Future Work

In this report we have presented both theoretical discussions on 3D printing from legal, social sciences and business literature and our empirical research conducted on 3D printing and IP utilising horizon scanning methods across six countries, combining the developed economies of France, Singapore and the UK with three BRICS economies, China, India and Russia. This has produced a rich picture of the state of play in 3D printing in these different places, its historical development and potential future trajectories, with recommendations drawn from both parts of this research for stakeholders looking forward.

In doing so we provide an insight into 3D printing and its interactions with other aspects of the global economy and society. However, we view research from business, legal and social sciences perspectives on 3D printing to be an ongoing process and see various avenues for future work beyond this report:

1. Continued research on 3D printing and its impact on the economy and society, and what this impact and interaction entail for legal regimes including, but not limited to, IP.

2. More research on 3D printing outside of developed economies/the West. There are important developments and initiatives taking place in the Middle East and Africa in particular but about which there is scant research.

3. Combined research on how different technologies including 3D printing are interacting with each other, and the implications of this interaction for the economy and society – rather than considerations of one particular technology by itself.

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