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The impact of 3D Printing Technology on the supply chain: Manufacturing and legal perspectives

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ABSTRACT

3D Printing (3DP) technology has been receiving increased public attention. Many companies are seeking ways to develop new means of creating and disseminating 3DP content, in order to capture new business opportunities. However, to date the true business opportunities of 3DP have not been completely uncovered. This research explores the challenges posed in the development and deployment of 3DP and focuses on China, which is still the main manufacturing hub of the world. The main purpose of this research is to uncover the obstacles that resist mass-scale applications of 3DP. By means of empirical semi-structured interviews with 3DP companies in China, it is found that many companies can see the benefits of 3DP, but its potential has not been delivered as promised. One reason is due to the fact that 3DP has not been integrated well in the supply chain. The other reason concerns potential intellectual property issues that cannot effectively prevent counterfeiting. To tackle the above issues, several areas have been identified that could be improved further. In particular, the legal complications concerning 3D-printed content could be overcome by a licensing platform.

1. Introduction

3D Printing (3DP) is a disruptive and innovative technology in the digital manufacturing era (Berman, 2012; Khajavi et al., 2014; Sasson and Johnson, 2015). 3DP is known as additive manufacturing, rapid manufacturing or direct digital manufacturing (Khajavi et al., 2014; Holmström et al., 2010; Sasson and Johnson, 2015; Rogers et al., 2016). It is a revolutionary digital technology utilising an abstract digital design file that can be transformed to a physical object by using a 3D printer.

The development of 3DP can be traced back to the 1980s (Khajavi et al., 2014; Rogers et al., 2016), but it is now more popular mainly because the process cost has reached an affordable level. This is particularly true for mass customisation and large-scale applications (Gosselin et al., 2016; Rayna and Striukova, 2016). 3DP is no longer distant from designers in the industry and is within easy reach of the public, including home users (Rayna and Striukova, 2016). A huge number of manufacturers, innovation companies, and even e-commerce companies have already benefited, or will benefit, from this technology. The expansion of the mobile communication industry and the Internet offers great opportunity for online 3DP platforms, the customised design service industry, and the 3DP content sharing community (Rayna et al., 2015). Moreover, the existence of 3DP technology accelerates the development of certain industries, for instance, spare parts manufacturing (Khajavi et al., 2014).

Despite the merits 3DP can potentially offer, it has not yet delivered its full capability to industry (Rogers et al., 2016). 3DP is not a technology to replace traditional manufacturing methods, at least in its current form from an operating cost perspective (Holweg, 2015). Arguably, energy consumption may pose an issue from a sustainability point of view, which is estimated to be one hundred times higher in 3DP processes than in traditional manufacturing processes (Yoon et al., 2014). This assertion is subject to debate as some other studies proposed the opposite (e.g., Gebler et al., 2014; Ford and Despeisse, 2016). Furthermore, legislation always follows, and lags behind, innovation. Copyright law is a classic example (Rideout, 2011). While a great number of individuals and companies are enjoying the benefits that 3DP can deliver, there is another group who is struggling with, if not suffering from, the Intellectual Property (IP) protection issues. All these obstacles hinder the applications of 3DP in the industry. There are lots of research studies that have investigated 3DP technology, especially in the material science and advanced manufacturing engineering disciplines. Nevertheless, such effort would become a waste if the technology cannot be deployed successfully in the industry.

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Broadly construed, there are three related gaps in research that can be identified from the literature to be presented in Section 2. The first one is that there is a need to understand the opportunities and challenges of using 3DP in industry. Although 3DP is a popular topic for discussion, the application of 3DP in the industry is still very limited. There are obvious obstacles that restrict 3DP from having an application on a larger scale. The technology itself is mature, which indicates that the application side could be the source of hurdles. The second research gap is an extension of the first research gap to supply chain management. There are many studies that advocate the use of 3DP, which can lower operating costs, reduce the amount of inventory, improve the ability of mass customisation, and provide quicker response to demand. Nevertheless, 3DP has not been integrated into supply chain processes. Replacement of traditional manufacturing processes alone cannot deliver the true value of 3DP. Innovative applications are required to boost mass scale applications of 3DP in the industry. The last research gap are IP issues, namely that the law that cannot prevent counterfeiting in 3DP applications effectively. This could also be one reason why 3DP has not been integrated into the supply chain yet.

The major objective of this study is to address two research questions: (1) the current application of 3DP technology in the industry and the associated challenges; and (2) from the legal perspective, how to protect innovative 3D-printed content in order to help improve the penetration of the technology within industry. Question one aims to understand why the adoption rate of 3DP technology in the industry is still low, and to uncover the associated challenges and obstacles. The second research question originated from the legal perspective and reveals how 3DP content can be protected in order to facilitate innovative applications of 3DP. Since this is an emerging topic, an exploratory qualitative approach is employed. To address the gaps and questions, evidence is collected using a systematic qualitative approach via semi-structured interviews. Details will be presented in subsequent sections.

The rest of this paper is organised as follows: Section 2 reviews relevant literature. Section 3 summarises the research method employed in this study, whereas Section 4 discusses the findings from 28 qualitative semi-structured interviews. Finally, Section 5 concludes this paper.

2. Literature review

2.1. Introduction to 3DP

Since 3DP is not a new concept, this section will only briefly review the technology itself from the manufacturing and supply chain perspective. The technical development of 3DP is not the focus of this paper. We mainly focus on the implementation and management of the 3DP technology in the industry.

3DP is a cost-effective solution for many applications, including home users, or Do-It-Yourself (DIY) users (Rideout, 2011; Doherty, 2012; Gao et al., 2015; Rayna and Striukova, 2016). From a business perspective, the technology can offer quick customised solutions, and create a great opportunity for made-to-order production (Gao et al., 2015). Even if the process costs may be higher than traditional manufacturing methods at this stage, the technological process can reduce other type of costs, such as inventory and warehouse costs. From a product design and quality management point of view, such technologies can phase in new revisions (be it due to upgrading of product features or fixing design quality issue) without scrapping obsolete inventory.

From a manufacturing and supply chain point of view, Holmström et al. (2014) opinion on the advantages of using 3DP are widely cited: (1) No tooling is needed significantly reducing production ramp-up time and expense; (2) Small production batches are feasible and economical; (3) Possibility to quickly change design; (4) Allows product to be optimised for function (for example optimised cooling channels); (5) Allows economical custom products (batch of one); (6) Possibility to reduce waste; (7) Potential for simpler supply chains; shorter lead times, lower inventories; and (8) Design customisation.

In addition, in the report “Made in China 2025” which was published by the China State Council in 2015, China has put the 3DP industry as one of the priorities in the first ten-year plan to upgrade the manufacturing industry (China State Council, 2015). Indeed, 3DP is a great challenge and also provides an extraordinary chance of historical improvement for traditional Chinese manufactures (Lipson and Kurman, 2013). Therefore, there is a need to understand the opportunities and challenges of using 3DP in China. D'Aveni (2013) predicted that the manufacturing edge of China would be fading out due to the 3DP technology. This is the reason why this study focuses on companies in China.

2.2. 3DP and supply chain

If we have started a new industrial revolution (*inter alia* digital manufacturing, Industry 4.0), 3DP is definitely a part of it and is considered as a game changer (Fawcett and Waller, 2014). 3DP production can be started on a made-to-order basis (Gao et al., 2015). This will reduce the amount of inventory stock up along a supply chain (Liu et al., 2014). In other words, excessive inventory stocking due to uncertain demand along a supply chain, known as the famous ‘Bullwhip Effect’ (Lee et al., 1997), should accordingly be reduced. If the ‘Bullwhip Effect’ is a critical problem in any supply chain, perhaps 3DP can be the solution?

Numerous studies have discussed the impact of 3DP on manufacturing and supply chain. The majority of these studies point to customisation (Eyers and Dotchev, 2010; Berman, 2012; Rayna et al., 2015). One extreme of the spectrum is, of course, to produce a quantity of one single unit. This was coined by Petrick and Simpson (2013) as “economies of one,” in contrast to economies of scale for mass production. Undoubtedly most companies will fall between the extremes of this spectrum. The implication, however, is that with the 3DP technology, the configuration of the supply chain and hence the associated business models would inevitably be changed. Customisation will allow easier product differentiation than the traditional supply chain models, and also allow for small quantity production by companies. Both features will change the way the traditional supply chain operates. One simple effect is that the number of suppliers can be reduced drastically due to the flexibility 3DP can deliver. In an extreme scenario, the only supplier would be the materials supplier for the 3DP process during the production phase (Mellor et al., 2014). The focus will be leaning more towards the customer end (Christopher and Ryals, 2014).

Since 3DP production can take place with minimum amount of labour involved, labour cost is less of an issue in view of the overall product cost. The location of production thus becomes less sensitive and there could be a re-shuffle of production facilities. For example, some factories may move back to the source of consumption, as with many developed countries (D'Aveni, 2013; Gebler et al., 2014; Mellor et al., 2014). At least the existing outsourcing models may change accordingly. This may also create a new paradigm of distributed manufacturing (Khajavi et al., 2014).

Another potential advantage of 3DP to the supply chain is that the technology can simplify some production processes (e.g. a module can be printed in one 3DP process rather than by assembling several components which may require different supply chains). It is a decentralized manufacturing technique that will alter distribution network. In this sense, the level of complexity and overhead required of a product or a supply chain can be reduced, and consequently the operation of the supply chain is more efficient (Holmström and Partanen, 2013), and the flexibility that 3DP offers more variety of end products. This efficiency can also be complemented by the increased quality for simplified parts or modules that the 3DP process can achieve compared to traditional labour intensive operations.

In practice, some large shipping companies and port authorities have started to encompass 3DP technology in their supply chain. For example, Maersk has installed 3D printers in their ships since 2014 to guarantee smooth operation in their shipping logistics. By utilising the technology's characteristic of print on demand, it solved any impromptu scenarios occurring due to malfunctioning mechanical ship parts. The technical support on the ship is able to immediate replace a spare part before reaching port. Meanwhile, the Port of Rotterdam has initiated 3D Fieldlab, to improve digital manufacturing infrastructure knowledge regarding additive manufacturing and to apply that knowledge to maritime and port-related industries (Port of Rotterdam, 2017).

Rogers et al. (2016) have provided a comprehensive review regarding the implications of 3DP on the supply chain. Therefore, the authors will not elaborate that point further and readers are referred to Rogers et al. (2016) for more details. The interesting findings from the literature is that the benefits of 3DP on manufacturing and supply chain management have been discussed widely, but there is limited evidence to demonstrate that successful mass scale applications of 3DP have taken place. In this connection, this research aims to explore this issue in order to uncover the challenges in deploying the 3DP technology.

2.3. 3DP and IP

3DP technology can be used to create any genre of product. Therefore, the ability to print unethical objects, such as lethal weapons or more specifically guns, would jeopardise public security and safety (Desai and Magliocca, 2013). Therefore, regulation should cover what should be, and what should not be, permissible objects to print. There has been much coverage in countries such as the UK and US on this point, with variable results (e.g., BBC News, 2018; Farivar, 2018). Nevertheless, this is not the core focus of this paper and hence no further discussion is made in this paper on this area of debate.

In addition, it is very easy to apply the technology to infringe IP in digital and analogue content, even if the users are infringing unintentionally. Due to the wide coverage of the Internet and the development of communication technology, the owners of printable content are able to upload files onto the Internet. Thus, interested individuals or companies are able to download the file without payment (Depoorter, 2013; Peacock, 2014). Afterwards, it is possible to redesign the downloaded content and print it out very easily. It might be acceptable if it is for individual use or educational use. However, there is a possibility that the newly printed content will go to the market for commercial reasons. Likewise, the contents of legally patented products are accessible to the public, who might print the products and sell exactly the same products to the market directly by scanning the objects. Larger companies have the resources available to them in assisting them with tracking the origin of printed goods shared without their permission, however, it is difficult for small and medium size enterprises (Lessig, 2001).

In principle, the design of any physical object could be capable of some form of IP protection, so any means of replication (e.g., scanning, in other words copying, a physical object and then printing it using a 3D printer) could be a breach of an IP right. The 3DP process is digital in nature so it is easier than ever before to “steal” a product design and then make small batch production. The situation is complicated by the current e-commerce technology. Imagine if these infringed products are sold online (e.g., e-bay or Taobao in China) - it is very difficult for the IP owners to track the origin of the infringement.

Additionally, 3DP processes and products differ from other ‘products’, like physical products, music, films, and so forth. The products are more complex and, currently, new to the public. For example, Chinese IP regulation has not yet covered this area. Meanwhile, many 3DP companies attempt to develop a new means of creating and disseminating 3D printed content utilising their 3DP systems and to capture new business opportunities. However, their opportunities have been limited because of the complex legal licensing environment, a lack of appropriate digital licensing standards, and the possibility of being held liable for the infringing acts of users.

In this connection, a proactive approach to protect copyrighted objects is more desirable (Rideout, 2011). In fact, many companies do respect IP, for example, by paying for the corresponding licensing fee. Without seeing real business potential, companies will not invest in 3DP though. In the UK, the relevant regulatory body called the Copyright Hub has set out a list of licensing standards to use in online licensing systems (El-Nazer, 2016). One objective of this research is to explore the appropriateness of these guidelines to the Chinese context, in order to propose a suitable licensing system in China.

2.4. Concluding remark from the review

This section briefly summarises the findings from the review and how they are related to the research questions discussed in Section 1. Many authors have discussed and suggested the merits of 3DP. Nevertheless, there is limited research to reveal mass applications of 3DP in the industry. Current applications are mainly to replace existing processes, rather than innovative application of 3DP. The situation is similar to the adoption of other technologies (e.g., RFID). Many interviewees considered that 3DP is an important element to pursue within a digital supply chain, but it can be achieved only if 3DP can be integrated into supply chains well. In addition, legislation does not provide sufficient support to protect 3D printed contents. The digital nature of the 3DP process make content infringement easy. This is analogous to downloading music or videos from web pages. Many people download the content without permission of the right holder (Gower, 2006). A licencing framework could be the solution, and coupled with current information technology, an online automatic licensing mechanism could promote the applications of 3DP. This can also facilitate the integration of 3DP into supply chains as well. In order to substantiate this, the study aims to discuss the opportunities and challenges of using 3DP from manufacturing and legal perspective. This is the first study in the literature to investigate these two perspectives and to suggest this solution.

3. Research design and method

Based on the reviews in Section 2.2 and Section 2.3, two research questions are investigated in this paper: (1) the current application of 3DP technology in the industry and the associated challenges; and (2) from a legal perspective how to protect 3D-printed content in order to help improve the penetration of the technology to the industry.

In order to address the above research questions, empirical qualitative data is required. The nature of the problem is exploratory in nature, and a qualitative type of research is more appropriate at this stage. In April 2016, 14 semi-structured interviews were thus conducted, each of which lasts for around 1 h. Another 14 semi-structure interviews were conducted in August 2016. Table A1 in the Appendix lists the 28 companies and their information.

The sampling of these interviews is chosen to cover companies that are related to various 3DP stakeholders. They could be printers, manufacturers, and so on. The natures of their business are: (1) Chinese 3DP manufacturer and 3DP distributor of foreign brands; (2) 3DP and scanning software suppliers; (3) 3DP material suppliers and material institutions; and (4) 3DP solution providers. The business area of the majority of the companies covers rapid prototyping and moulding of fashion products, mass customisation of spare parts (in ships, jet engines, and aerospace), and for education science training. The companies interviewed are located in major industrial areas in China including Beijing, Shanghai, Guangzhou, Hangzhou and Ningbo. The interviewees are either founders, general managers, legal officers or technical managers who have good understanding on the 3DP operation and business in China.

4. Findings and discussions

4.1. 3DP and supply chain

Our initial questions are related to the application of 3DP in the manufacturing and supply chain sectors. This serves to confirm the potential capability of 3DP to the industry, and to explore the challenges faced by the industry. Generally, the responses about the application of 3DP are positive. In particular, three areas can be identified which are discussed further in the following sub-sections.

4.1.1. R&D and design

Although material costs and operating costs of the 3DP process may still be higher than traditional manufacturing process, it is generally agreed that 3DP can help reduce the development cost of products. Interviewee 2 stated that "*3DP does have some significant impact in some industries. It is mainly because with 3DP technology, it will improve efficiency and significantly lower the cost*". In addition, 3DP can shorten the development time drastically. It is because, according to interviewee 22, "*traditionally you have to design the machine and mould based on what you like to produce, but 3DP changes the old way so that you don't have to design them*". Interviewee 18 supplemented this, by stating that "*it is a waste to develop a prototype and mould by using conventional method. 3DP can stand out and give you an economic solution*" in this aspect. This is also the early utilisation of 3DP, i.e., rapid prototyping.

One of the interviewees, interviewee 5, provides such a service to foreign trading customers. When the company receives a physical sample from the customers, they scan it and then 3D-print it out. It is even easier if the customers can provide the company with a digital file. This is a new business model that can provide a fast turnaround time to the end customers without any tooling. This business model enables the customers to modify the design based on the 3D-printed samples and they can get the revised version very quickly. With such physical samples, the customers can minimise the risks in the product design process. They can also order a number of samples with different design options for testing at the same time, without expending extreme effort. Interviewee 7 mentioned that a WiFi device took half a year to progress through the tooling fabrication and testing phases, not to mention the high tooling cost involved. 3DP can also reduce both development lead time and associated costs.

The main implication of this area is that it is easier to produce a new product in smaller quantities with relatively affordable capital, by using 3DP technology. It is also easier to build a new brand in the market, and this is particularly favourable to small and start-up companies. With the assistance of 3DP, companies can then move from Original Equipment Manufacturing (OEM) or contract manufacturing to Original Design Manufacturing (ODM). In ODM manufacturing mode, designers and manufacturers in the value chain must communicate and collaborate during the manufacturing process. Liao et al. (2017) have proved that supply chain collaboration enhances innovation of firms, which eventually provide a competitive advantage (Liao et al., 2017). This is exactly what the 'Made-in-China 2025' initiative would like to achieve in China. However, how such start-ups and small companies, normally faced with limited resources, can protect their IP and ensure that the design is free from infringement, is another challenge that we will discuss further in a subsequent section.

4.1.2. Manufacturing and supply chain

Notwithstanding the cost benefit 3DP can bring to the product design process, the shortcoming of 3DP aligns with the reported studies that the unit manufacturing cost is still significantly higher than the traditional counterpart. This is still the major barrier in achieving the full potential of 3DP. In other words, there is a pressing need to incorporate additional value in the 3D printed parts or components to compensate for this high cost. For example, 3DP is (almost) mould-free. This characteristic of 3DP can reduce the maintenance costs and tooling costs of moulds, which can bring some benefits to some industries. According to interviewee 22, the next question is how to leverage costs, such as economy of scale from mass production. This is also echoed by interviewee 18, that in some industries "*current moulding is quite convenient and we can make it cheap and nice*".

One way to counteract the barrier is to employ 3DP in a different manufacturing or supply chain. Mass customisation has unanimously been considered the merit of 3DP in manufacturing and supply chain. Interviewee 16 and interviewee 21 both confirmed that small batch production is more feasible with 3DP, especially when the demand is uncertain. 3DP allows for product differentiation. Interviewee 2 gave an example of car headlights in his production line. There could be six options that mean the companies needed to stock up inventory for six stock-keeping units. It is costly and timing consuming to design and manage the corresponding moulds. With 3DP, interviewee 2 can take just one week to finish this task. Another way to further enhance the productivity of the 3DP industry could be to set up a service centre for 3DP. Interviewee 12 stated "*this centre will serve the local enterprises to enhance their competitiveness*".

Based on the interviews, 3DP cannot only reduce cost and time of product development and manufacturing, but help counteract the uncertainty of demand since the supply chain can be more responsive. This is because production can take place at a unit quantity level. Manufacturers do not need to stock up different types of materials other than the materials for 3DP, which can be used to produce different types of parts and products. Effectively, there is no need to manage the supply chain in this sense. Demand for the materials is aggregated by the technology itself, even if the demand information is not available to the manufacturers and the suppliers. To achieve this paradigm is of course not easy and currently the industry is still far from this. However, the ability to introducing customisation can help manage the demand uncertainty of the supply chains. This is especially important with the current pace of technological development that leads to fast changing customer demand.

Another obvious barrier to apply 3DP in the industry is the recognition of the technology to some industries. This is somehow related to the cost of 3D-printed parts, and the material in relation to printing. Industries with high value products, such as the medical and automobile industries, can more easily incorporate 3DP in their manufacturing process. Some interesting industries, such as glass production, do not even require tooling. Therefore, the added value of using 3DP technology would be very much dependent on the time and cost to print a product or parts within particular industries.

4.1.3. Data management

Coupled with the capability of customisation, good data management can facilitate 3DP, and vice versa. It is because the value behind the customisation is customer preference and behaviour. Interviewee 15 worked with her customers, in that data from those customers who, in turn, obtained scanned data via the cloud, are synchronised. This allowed interviewee 15 to work on the data and revise the design. This allowed interviewee 15 to make sure that the design is truly customised and would not infringe other designs in the database. Obviously, this links to the IP issues that will be discussed in the subsequent section. Regardless of the IP issues, this way to exchange information is not restricted to the product design for printing. For example, interviewee 18 also incorporated patients' information so that the medical products produced by them can be easily customised for the next generations of products. This aligns with the recent big data research and analysis trends. That alignment can help companies to trace 3D-printed contents along the supply chain, according to interviewee 19. This can further assist mass customisation mentioned above because this really can achieve the no-supply-chain utopia.

4.2. 3DP and IP protection

The next set of questions is to investigate how IP issues would effect the deployment of 3DP technology to the industry, and if so, how this challenge can be overcome. Through the semi-structured interviews, we are able to understand the current phenomenon of legal issues regarding the 3DP industry. One major reason behind the unregulated environment in China's 3DP industry is due to fact that the industry is dynamic, fast growing, but on a very limited scale and which is, currently, unable to regulate itself. Roughly speaking, half of the interviewed companies are completely ignorant of Intellectual Property Rights (IPR). For those who are interested in IPR, they mainly concern patents. Interviewee 2 said: "*Good patents always lead to good product lines. A good product means a big market*". The reason is obvious as patents can help them to protect the business in terms of profits, and refrain, or at least delay, their competitors from reaching the market. The only distinctive segment that is more aware and knowledgeable of the law is those companies producing medical parts or devices.

According to an interviewee, the local market experienced a rapid growth in 2012 under multiple incentive policies from the Chinese government and exaggerated promotion of media has attracted a lot of players from various dissimilar fields. According to another interviewee who is also an entrepreneur from a leading company, the local government attracts industry newcomers with lucrative packages, which include three years' exemption of office rental and monetary reward for IP awarded 3D technology. He further commented, "The biggest problem in China's 3DP industry is that it is with very low entry barrier with very niche market. The competition in this industry is very fierce because of the exaggeration of media that demonstrates public an illusion of the idea that the 3DP industry is the future. The reality is always cruelly disparate, in order to survive in the market, low price strategy is the only strategy. Thus, low quality and patent troll [s] are the outcomes."

On the other hand, the process and content of 3DP products are different from many other traditional objects or services, as they are more complex. There are difficulties in tracing the origins of source materials, as reflected from the interviews with bio-printing companies. Moreover, the nature of IP law is complicated, and when old laws meet new technology, it is often the case that legislation is unable to fit into the new eco-system. Therefore, it is difficult to offer effective protection.

The majority of the interviewed companies responded that legal protection of contract law has covered the rights and interested of companies, whose role resemble service providers based on the items provided by the customers. The customers have to agree with the service providers that they are not responsible on the IP of the items. There is no incentive for companies to trace the originality of the item when they are already protected under the contract law's umbrella. A general manager of a local B2B manufacturer, stated that, "There is no way for us to trace the originality of the content given by customer. For instance, if someone gives us an iPhone, we will know that it is from Apple. However, most of the time when the product is received, we have no idea where or who the product/content belongs to. Furthermore, the bargaining power of customers is always stronger than us, if we emphasised too much on content originality, the customer can always choose to go for another company who does not ask for originality to complete the printing. We are too weak to pursue for intellectual property when there is lack of practical guidance on the law in the industry."

At the same time, there are also some companies we interviewed who already saw the importance of IP protection of 3DP products. The chairman of a 3DP association in Hangzhou has adopted a creative method to encourage open source printable content designers to continuously contribute their innovation to an open source platform, where he allocates "profit share for content designer" after the product goes to mass production. The corresponding designer receives reward for their creativity. In the meantime, the manufacturer would change the image of "Made in China", which sometimes can indicate an infringement IP product, to "Created in China". The companies could strengthen their brand reputation and image by selling authorised 3D products. This is a "win-win-win" situation. He commented, "Open source is the future, there will be only two types of factories in future, one is for printing material and another for production. We can produce everything at any time and are able to supply to the whole world. Till then, the standard and regulation of IP will automatically be set. If IP law applies at this dynamic stage, it will discourage designers to free their mind, there will be no imagination, then the industry will end."

The value chain of 3DP is straightforward, with the combination of equipment vendors, distributors and resellers, service providers, and also, material and software providers. When discussing the relationship between IP and technology, there are various formulations of IP, for instance, copyright, patent, trademark, registered design and utility patent. All of these terms are related to different value chain. An interviewee from a 3DP materials research institution proved that, "We update our hardware frequently so we will not apply a patent for every stage's incremental improvement, we would also keep as trade secrets by not disclosing to the public. Furthermore, if someone wants to use our equipment, he only needs our formal license on the application of the technology but not on the intellectual of product because the product is only the result of mass production, which does not follow the nature of the patent right."

Nowadays, it is easier to access and obtain digital content due to the availability of file sharing. More importantly, this allows individuals to obtain digital printable content online without any payment to the content owner. Individuals can then customise and print an object for personal purposes. This leads to serious brand dilution as there is no way for a company to track counterfeiting. It is also extremely difficult to detect infringing activities which lead to prohibited usage of an IP protected item. This is complicated by a lack of IP standards and regulation for the 3DP industry.

In fact, the cost to protect IP for 3DP applications is very high, not to mention that it is very time consuming, as a heavy workload is required. This creates conflicts between innovation and business opportunities. With the establishment of an automatic single licensing online platform, all the IP content is automatically protected. Users of 3DP content pay a small amount every time they access the content via the platform, e.g. through advertising (like those on YouTube) or through the monitoring of use (e.g. Facebook). Meanwhile, the right holder receives reward of their innovative works by *inter alia* automated pay-per-click downloads, and are able to track the usage activities of whom, where and how is their IP are being used. This couples with recent trend in 'big-data' analysis.

From the industry's perspective, the automatic licensing method protects the originality of companies' products which exempt IP-cautious applicants from complex and confusing legal terms. Consequently, this encourages innovators to innovate under the protection of a flexible and less intrusive legal system. Under this system, all the stakeholders in the industry are more disciplined to avoid legal disputes, as regulation and standards will set in automatically to work as a regulator. From the interviews, it is commonly agreed that a watermarking system can be utilised to protect 3DP content. One method to execute this is to "add" a watermark on the 3DP content that can be recognised later. Then, licensed 3DP content can be distinguished. This system can be operated online automatically. In this connection, this is the extension of this exploratory study to develop such watermarking technology.[1]

[1] The watermarking technology has been filed for invention patent application in China (Application number is 2017104694528).

5. Conclusions

The main implication of this study, via the semi-structured interviews, is that 3PD is not yet ready for mass scale applications. Although many practitioners can visualise the benefits and potential impacts of 3PD, it has not been as widely deployed as many studies predicted. Many players are reluctant to integrate it into their supply chain processes. It is still too early to conclude that the mass production era has been replaced by the mass customisation era. In fact, the opposite is probably more accurate according to the interviews. 3DP has created a lot of 'hopes' but at this stage 3DP has still not fully delivered its promise. The key message from the interviews is that in order to fully extract the value of 3DP, it cannot be used to replace existing processes. Innovative design such as open platforms with a good data management system would be feasible route to incorporate 3DP in the digital supply chain era. This will introduce innovative usage of the 3DP processes, rather than manufacturing. Such system can be blended with the proposed automatic licensing system that can counteract IP protection issues. This is the first study to investigate these issues in the field.

Nonetheless, this study also argues that 3DP itself, among other technologies and technological development, enables the transition. The authors do not assert that the mass production type of methods will be entirely phased out, but it will be complemented by the demand for mass customisation. This is supported by interviewee 21: "*I don't think it (3DP) can replace the traditional manufacture*". However, many interviewees predict that as more 3PD service providers or manufacturers will appear in the market, but 3DP that is easier to incorporate into various manufacturing and supply chain applications.

Another managerial implication confirmed from this study is that there is a need to protect the IP in 3DP content. An online automated licensing platform, where content is IP protected, is proposed. The licensing platform could regulate authorised 3DP by tracking content and product information throughout the value chain. The proposed platform will be supported by watermarking technology for 3DP content, which is under invention patent application, discussed at the end of Section 4. The main objective is to prove the proposed concept is feasible and to resolve any technical barriers when the concept is used in real applications. This system is a proof-of-concept, and if successful can be extended to a real commercial system, analogous to the UK Digital Copyright Hub system.

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Appendix

Table A1
List of Companies

	Position of the interviewee	Company Location	Business Scope	Years since established	Company Size (number of employee)	Market
1	CEO	Ningbo	3D printer and robot production	< 5years	< 10 employees	National
2	CEO and CTO	Ningbo	3D printer production and 3D maker online community	< 5years	10-20 employees	National
3	Senior officer	China	State owned R&D Institution specialised in new materials and advanced manufacturing	14 years	N/A	Regional
4	CEO & founder	Ningbo	Foreign 3D printer brand distributor	< 5years	< 10 employees	National
5	Founder and Chairman	Hunan	One stop solution provider of industrial grade materials	9 years	> 100 employee	Multinational
6	Deputy of General Manager	Ningbo	3D printing service provider	< 5years	~15 employees	National
7	Marketing	Ningbo	3D printing service provider	< 5years	< 10 employees	National
8	CEO & founder	Hangzhou	Cloud printing service provider	< 5years	~20 employees	National
9	CEO & founder	Hangzhou	3D Scanning service provider and 3D Scanner distributor	< 5years	~15 employees	National
10	CEO & founder	Ningbo	3D printing software provider, IP application service agent	< 5years	< 10 employees	National
11	CEO	Hangzhou	Construction 3D printing	< 5years	< 10 employees	CHINA & US
12	Manager	Shanghai	Online 3D printing store and 3D printing service provider for Marine industry	10 years	50-60 employees	National
13	Manager	Shanghai	3D printing in metal service provider	5–10 years	~15 employees	National
14	Sales manager	Shanghai	3D printer part: Optical engine design and manufacturing	< 20 years	< 10 employees	CHINA & US
15	CEO	Beijing	One stop advance manufacturing solution provider	2004	20-30 employees	National
16	CEO & founder	Beijing	3D design and scanning	< 5years	< 10 employees	National
17	Marketing Director	Beijing	3D printing service provider	< 5years	< 10 employees	National
18	CTO	Beijing	3D design online community	< 5years	30-40 employees	National
19	Director of research	Suzhou	Bio-printing	2 years	> 60 employees	National
20	Chairman	Shanghai	Regional 3D printing association	3 years	N/A	National

(*continued on next page*)

Table A1 (*continued*)

	Position of the interviewee	Company Location	Business Scope	Years since established	Company Size (number of employee)	Market
21	President	Shanghai	Distributor of 3D printing material and 3d printing equipment	> 10 years	30-40 employees	National
22	Sales Director	Shanghai	3D printing solution provider	< 5years	20-30 employees	CHINA & US
23	Legal specialist	Shanghai	3D printing software provider to medical and manufacturing industry	Since 1990	multinational	Multinational
24	Professor	Guangzhou	University's research institution	Since 1958	N/A	N/A
25	CEO & founder	Guangzhou	One stop 3D printing solution provider	< 5years	20-30 employees	Regional
26	CEO & founder	Guangzhou	3D printer and 3D printer component production	< 5years	~15 employees	multinational
27	CEO and CTO	Guangzhou	Private Research Institution	8 years	N/A	N/A
28	President	Qingdao	Largest 3D printing association in China	3 years	N/A	International

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