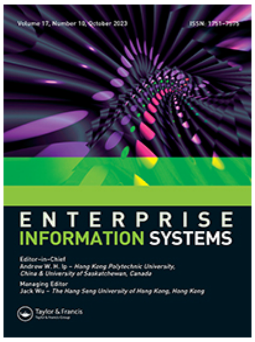

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Blockchain-enabled authentication platform for the protection of 3D printing intellectual property: a conceptual framework study

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ABSTRACT

3D printing (3DP) has enjoyed rapid growth yet has also prompted ethical and social concerns. For example, the ability to print unethical objects and intellectual property (IP) infringement. This paper follows the dual-cycle information system design model and implements a multi-method to propose a blockchain-enabled digital platform solution to protect 3DP digital assets' IP. It combines the advantages of patented watermarking technology and blockchain technology, including encryption, authentication, and transaction services of 3DP designs according to users' needs. The platform may help promote the standardised development of the 3DP industry and the international digital assets' IP protection process.

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3D printing; intellectual property rights; blockchain; conceptual platform framework

1. Introduction

The past few decades have witnessed the rapid development of disruptive technologies like the 3D printing (3DP) industry in terms of the increased industry size, the further segmented industrial market, and the shifting of the industrial focus towards midstream and downstream sectors. According to the industrial report from Associates (2021), the global market size of 3DP in 2020 reached $12.8 billion. The agile 3DP-supported supply chain facilities firms maintain competitiveness and meet fast-changing customer demands in the current business environment. However, it also requires a closer inter-organisational relationship featuring constant communication and collaboration for manufacturers and designers in the value chain (Chan et al. 2018). One of the major barriers to information exchange and cooperation is the issue of protecting intellectual property (IP) during the digital era.

The intellectual property industry has long suffered from the prolonged period and difficulties in authorising and protecting IP rights and realising the profit (Alikhan and Anant Mashelkar 2009; Shavell and Van Ypersele 2001; Council, National Research 2000). Digital data, such as the 3DP design, is characterised as a large amount of data, real-time, relies heavily on electronic devices, easy-to-tamper and lose and so like, making it

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more difficult as evidence for IP rights (Ekbia et al. 2015; Cavanillas, Curry, and Wahlster 2016). The openness of the Internet and characteristics of 3DP designs, such as the value of co-creation, sharing and co-ownership, further impede the evidence collection and responsibility confirmation for the infringement of digital IP rights. As a result, there are growing demands from innovators and creators for the adequate protection of their digital products (Chan et al. 2018). Due to the lack of an existing solution to offer protection for IP in the 3DP supply chain, the development of distributed 3DP production networks for established products has been inhibited (Holmström et al. 2016; Kurfess and Cass 2014). Various IP-related risks can partially contribute to the situation that 3DP has not yet realised its full commercial potential (Gao et al. 2015; Chan et al. 2018; Yampolskiy et al. 2018).

The blockchain is a publicly distributed ledger that can record transactions between multiple parties efficiently, verifiably, and permanently on thousands of nodes around the world simultaneously (Lakhani and Iansiti 2017). Prior studies show that blockchain technology can greatly facilitate data transformation and secure sharing along supply chains due to blockchains' immutability of records, low risk of downtime, and censorship and data falsification (Nakamoto 2008; Beck et al. 2017; Li, Vatankhah Barenji, and Huang 2018; Wang, Hugh Han, and Beynon-Davies 2019; Ivanov, Dolgui, and Sokolov 2019). Blockchains offer significant potential in overcoming 3DP design information tracking and authentication. However, blockchain technology alone is no silver bullet. Gaps still exist regarding its application in IP encryption, authentication, and transaction, as a blockchain tends to help guarantee the reliability of data transformation and comparison.

In contrast, a licencing system and a channel for 3DP digital assets' IP protection, as proposed by Chan et al. (2018), that leverages multiple data sources and integrate various systems are still needed to complete the authentication solution. To this end, we propose the design and use of a digital platform. A platform can be referred to as a 'sociotechnical assemblage encompassing the technical elements (both software and hardware) and associated multi-sided organisational processes' (Tilson, Sorensen, and Lyytinen 2012, 752). Its inherent characteristics, like openness, customisability, and real-time interaction without geographical and temporal limitations (de Reuver, Mark, and Basole 2018), make it an ideal integrated channel for 3DP digital assets' IP encryption, authentication, and transaction. Thus, the construction of a blockchain-enabled platform can combine the virtues of blockchain technology and the platform's openness for 3DP digital assets' IP protection and authentication in accurate and easy-to-use ways.

In response to the assertion that IP protection is one of the major barriers preventing supply chains from the mass adoption of 3DP and that a licencing and authentication platform is necessary (Chan et al. 2018), this paper addresses how blockchain technology can help solve the abovementioned problems and how a platform would help it. Specifically, the framed research questions are: (1) What are practitioners' (especially for SMEs) concerns and requirements for designing a 3DP IP rights protection platform? (2) How to merge the advances of the blockchain technique and construct a 3DP IP rights protection platform? The study, therefore, collects the system functional requirements from the semi-structural interview and follows the information system design process to construct the conceptual framework of the blockchain-enabled 3DP IP rights protection platform.

The study constructs a conceptual framework of a blockchain-enabled IP protection platform for 3DP according to the methodology outlined by Meredith (1993). This paper is organised as follows: Section 2 reviews the current state of 3DP digital assets' IP and the challenges it faces within supply chains, blockchain technology, and platform applications. Section 3 presents the research method of the study and the requirements acquisition for creating or improving a 3DP digital assets' IP protection solution via empirical interviews with business practitioners. Based on these inputs, the conceptual system infrastructure used for both the business process flow and the information flow of a blockchain-enabled 3DP digital assets' IP protection platform is designed in Section 4. Section 5 presents the implications of the study. Finally, section 6 concludes the research and provides an outlook for further developments of 3DP digital assets' IP and the mass adoption of 3DP.

2. Literature review

2.1. 3DP IP and related challenges in the supply chains

The 3DP process is digital in nature. For example, the construction model must be created, iteratively optimised, and tested for the 3D model to be created. Therefore, sensitive processing and manufacturing data emerge in this 3DP process, and a digital thread is created, namely, the 'information path that is gathered and stored when manufacturing a single part' (Kim et al. 2015, 2). It is much easier to 'steal' digital product designs and reproduce them in small batches than with their analogue counterparts (Chan et al. 2018).

Meanwhile, the nature of 3DP products includes data exchange at a granular level between manufacturers and clients, which requires a focus on confidentiality, for example, when manufacturing medical 3DP products. Likewise, using 3DP for consumer-oriented production and co-creation could include asking customers for their data (Naghshineh et al. 2020). Under the umbrella of 'open innovation', 3DP technology promotes community members' participation in sharing their ideas and outcomes (Naghshineh et al. 2020). But it brings implications of legal disputes in unregulated contexts, resulting in IP infringement.

The ubiquity of the Internet and the widespread use of ICT enables owners of printable content to upload files to the Internet, from where individuals or companies can download the files for free. After that, it is easy to redesign the downloaded content and print out the product. This means that a newly printed product can enter the market immediately. Even a product protected by a legitimate patent, trademark, or copyright can be scanned and sold directly. While large companies have the capability to trace the source of printed copies, it is challenging for small- and medium-sized enterprises (SMEs) to do so (Lessig 2002). The current popularity of e-commerce makes the situation more complicated. When infringing products are sold via e-commerce channels (e.g. eBay or China's Taobao), it is difficult for IP owners to trace their source. In a B2B context, the risk of losing IP prevents information exchange and collaboration in inter-firm relationships, and the inability of existing solutions to protect IP limits the growth of decentralised and localised 3DP manufacturing networks (Holmström et al. 2016; Kurfess and Cass 2014).

Moreover, supply chains increasingly represent value-added networks nowadays (Borsato and Peruzzini 2015). The distributed development of printed parts is another challenge when there is a critical need to distinguish between 'original part', 'copy', and 'counterfeit' components or products. It is particularly relevant for safety-critical products. According to Gao et al. (2015), data manipulation, infringement, and theft pose great challenges for 3DP supply chains in the digital age. The above discussion indicates the need to protect 3DP IP.

2.2. Blockchain technology

2.2.1. Blockchain applications in intellectual property-related areas

The potentials of blockchain technology have been explored in various industries (Kouhizadeh and Sarkis 2018). Generally, a blockchain can be understood as a novel way of managing decentralised data. It can be seen as a publicly accessible distributed ledger, allowing for the integrity of all types of transactions. Each transaction is time-stamped and resides in a linearly sequenced and secured block, where the latest transaction incorporates the information of all previous ones (Wüst and Gervais 2018). Implementing blockchains creates a decentralised network, opening up opportunities to foster trust between parties without involving a third party (Swan 2015).

Meanwhile, the distributed shared ledger can replicate its content on thousands of nodes. As long as most ledgers can outnumber corrupted and manipulated information, the accuracy of transactions or information can be ensured, and trust shifts towards multiple copies (Franco et al. 2019). Thus, it can be argued that the immutability of data and how information is generated, structured, and distributed explain the trust established between unknown participants (Omran et al. 2017). As a result, blockchains offer benefits in terms of the immutability of records, security, the authenticity of digital information, data ownership, and transaction transparency, and there's an inherent degree of trust (Beck et al. 2016; Christidis and Devetsikiotis 2016). Consequently, blockchain-enabled IoT services can be implemented to enhance trust in the IoT context (Viriyasitavat et al. 2022).

Besides, its critical functions, such as cryptocurrency and smart contracting, have enabled myriad innovative measures (Choi and Luo 2019). Recently, innovative initiatives include exploring the role of blockchains in addressing IP-related issues. Among them are the design of a blockchain-based IP copyright protection algorithm in real-time circuit copyright authentication (Liang et al. 2020) and IP circuit trading (Xiao et al. 2020). Regarding protecting digital music copyright, Cai (2020) constructed a digital music copyright protection system by combining deep learning and blockchains. To protect image copyright, immutable hash values become a critical component using perceptual hash technology and digital watermarking (Meng et al. 2018).

Meanwhile, general visibility can be achieved during the design phase by preserving the components' historical records and securing the prototypes' authentication. Choi (2019) illustrated how the blockchain platform is deployed for diamond authentication using the case of Everledger, claiming the platform would incur blockchains-enabled diamond authentication and certification cost and reducing it is key to benefit all involved supply chain parties. Zeilinger (2018) exemplified the use of the blockchain platform in developing proprietary digital art markets, in which the uncommodifiable nature of digital art is monetised as an artificially scarce commodity.

Similarly, concerning the creation and lifetime of products or services, Casino, Dasaklis, and Patsakis (2019) proposed using blockchain integrity verification applications, which store information and transaction of the products or services. Provenance, counterfeiting, and IP management are some of the potential applications. Recently, in the review papers, both Lu (2021) and Dutta et al. (2020) pointed out the potential of blockchains in IP management. However, very limited studies exist to explore the benefits of blockchain to address IP rights as a decentralised solution.

2.2.2. Blockchain and 3DP-related areas

Given the characteristics above, scholars have devoted their attention to how blockchains can be leveraged to protect IP in the 3DP industry, which has become increasingly complicated in today's digital age. To begin with, the creation and exchange of digital files, such as CAD files (Chen et al. 2015), can potentially result in leakage in the 3DP supply chain. In response, the record-keeping feature of blockchains could be a plausible solution to ensure the confidentiality of 3DP designs and minimise risk exposure. In a similar vein, Klöckner et al. (2020) argued that blockchains can mitigate IP and data security impediments related to 3DP in the form of distributed copies in the blockchain. It promotes information symmetry and increases supply chain visibility (Kurpjuweit et al. 2021). Holland, Nigischer, and Stjepandić (2017) and Holland, Stjepandić, and Nigischer (2018) claimed that blockchains and digital rights management are key enablers for developing 3DP methods and major contributors to 3DP commercial development and the prevention of IP theft for 3DP supply chain. Scholars discussed establishing a secure additive manufacturing platform (SAMPL), which incorporates secure chains of trust for 3DP procedures.

Despite the insights offered by these prior studies, the role of blockchains has not been explored holistically to contribute to 3D digital design IP protection. Besides, despite the potential applications of blockchain technology in 3D intellectual property, it is not without challenges, such as the immaturity of blockchain technology, scalability problem and a lack of stakeholder awareness of 3DP IP protection in the industries. Further, the 3D digital design contains a large amount of data and is easy to tamper with and lose. Given that existing blockchain technology alone may not effectively address the risk to IP rights in 3D digital design, it is imperative to provide a blockchain-enabled solution that can potentially address encryption, authentication, and transaction issues of 3DP designs. Based on the preceding discussion, a knowledge gap exists regarding how blockchains can be integrated with other potential solutions to address the IP problems of 3D printed products effectively.

2.3. Platform application

Initially used in product development, platforms have been widely applied due to their benefits, especially in the service design field (Fu, Wang, and Zhao 2018; Voss and Hsuan 2009; Meyera and DeToreb 2001). These services include e-commerce services (Mahadevan 2000), Internet-based services (Daim, Brand, and Lin 2011), and government public services (Brown et al. 2017). As services entail a close interactive relationship with customers, a platform allows organisations to increase the responsiveness and flexibility with which they meet their users' needs (Sawhney 1998) and to enhance the service or product they provide (Pil and Cohen 2006).

As the pace of digitalisation has increased, extensive research has enriched our knowledge base of different types of digital platforms (e.g. Gawer 2020; de Reuver, Mark, and Basole 2018). Digital platforms share three fundamental characteristics: 'they are technologically mediated, enable interaction between user groups and allow those user groups to carry out defined tasks' (Bonina et al. 2021, 3). Depending on the platform's field, it can have various definitions. We adhered to the definition of Tilson, Lyytinen, and Sørensen (2010) mentioned above. As digital platforms enable interaction between multiple user groups, they create network effects, which implies that a platform's value or usefulness increases when the number of users grows (Shapiro, Shapiro, and Varian 1998). Combined with a thin asset layer, such network effects provide opportunities to disrupt existing industries (Nishikawa and Orsato 2021). For example, Uber considerably disrupted the taxi industry within just a few years of its inception. The more drivers and users are included, the more drivers or users will be attracted. A platform's usefulness can also increase when adoption levels yield positive feedback cycles (Arthur 1989). During this process, new and existing users can also benefit from lower prices and less uncertainty about future platform development, new market opportunities, and high-quality products (Dew and Read 2007). More importantly, platforms have served as an important channel for value co-creation amongst multiple actors (Xiong et al. 2022). A digital platform's capability to generate a network effect depends on its openness, not limited to organisational arrangements such as entrance and exit policies, technology openness like application programming interfaces (APIs) and software development kits. For example, platforms that integrate data sources and devices grow as application development becomes more accessible (Nikayin and De Reuver 2013).

The underlying technical properties of platforms depend on their purpose and type. Generally, there are two broad types of digital platforms: innovation platforms and transaction platforms. Innovation platforms consist of modules in the modular architecture (Ulrich 1995). Modules are divided into core and periphery modules (Baldwin and Jason Woodard 2009). Modules in the core could be mostly sourced from the platform authority. Prominent examples are mobile operating systems such as iOS and Android, Amazon Web Services, and enterprise platforms like SAP and Salesforce. The nature of innovation platforms is that various functionalities and interfaces provide fertile ground for a diverse, generative scope of different innovations.

Transaction platforms, also referred to as exchange platforms or multi-sided markets, aim to facilitate transactions between suppliers and buyers who could not connect easily (Zeng, Khan, and De Silva 2019). The declining costs and enormous processing power and memory capacity have facilitated the development of cloud-based infrastructure. Transaction platforms often host in such cloud infrastructure. Consequently, the information and processes they can store can expand at an unlimited rate (Faulkner and Runde 2011, 2019). In addition to notable transaction platforms like JD.com and Taobao online marketplace, social media platforms are examples of transaction platforms. They gain profits by monetising their users' data and sourcing it for target advertisers (Zuboff 2015). It is worth noting that the platform could evolve depending on the levels of architectural openness and the types of platforms. For example, manufacturers could gradually invest in platform architecture to enrich platform services and functionalities (Jovanovic, Sjödin, and Parida 2021; Thomas, Autio, and Gann 2014).

Through leveraging the characteristics of platforms and blockchains, blockchain-based platforms have already contributed to the IP protection of digital assets. For instance, to ensure safe mould design knowledge transfer and licencing, Li et al. (2019) proposed a knowledge-sharing platform that integrates a blockchain and a private cloud to store the knowledge. Similarly, Liang et al. (2020) suggested a blockchain-based platform to cut transmission costs and enhance the efficiency of circuit design data supervision and storage. Nevertheless, how the platform can be developed with potential technologies for 3DP protection is far from being established by scholars and practitioners, especially considering that the platform could evolve and develop to provide more functionalities to meet ever-increasing customer requirements.

Based on the previous discussions, there is a lack of research on embedding blockchains into a platform by leveraging their advantages to solve 3DP intellectual property issues. To address this gap, the objective of our study is to propose a platform framework in this regard. For instance, how firms use the platform to keep records of their 3D printed parts and how those data can be further used to create additional value for customers to carry out a transaction of 3D printed products without any concern over potential IP conflicts. This study is also responding to the call of Zheng and Lu (2021)for more research on 'blockchain tertiary industry service models, and blockchain-related businesses or industries' (p. 13) and the call of Dutta et al. (2020) for more profound research on the role of blockchain in IP right management.

3. Industrial evidence

The previous section serves as the theoretical foundation of this study, and this part provides the industrial evidence with practitioners from the 3DP industry. Both of which direct to the needs and the mechanism of the platform this study proposes. Here in this part, we mainly explore the issues that remained in 3DP digital assets' IP protection and the process of 3DP service, which are believed to provide a deeper understanding of the IP protection of 3DP.

3.1. Method and research framework

The method and research framework of the study followed the dual-cycle information system design model proposed by Gasson (2003). The model includes multi-method: i.e. semi-structured interview and system framework design. This is shown in Figure 1. Following Zeng, Kai Chan, and Pawar (2021) method, semi-structured interviews were employed. An interview is considered one of the most crucial sources for collecting evidence. A semi-structured interview is one of the most-used techniques in business and management research (Myers 2019). Therefore, this research method is used in this study to explore the view of practitioners on IP protection in 3DP and the business process of 3DP service. Then the conceptual platform framework design process is implemented to respond to the industrial requirements based on existing blockchain with encryption techniques. Finally, the study's findings offer the practical and academic

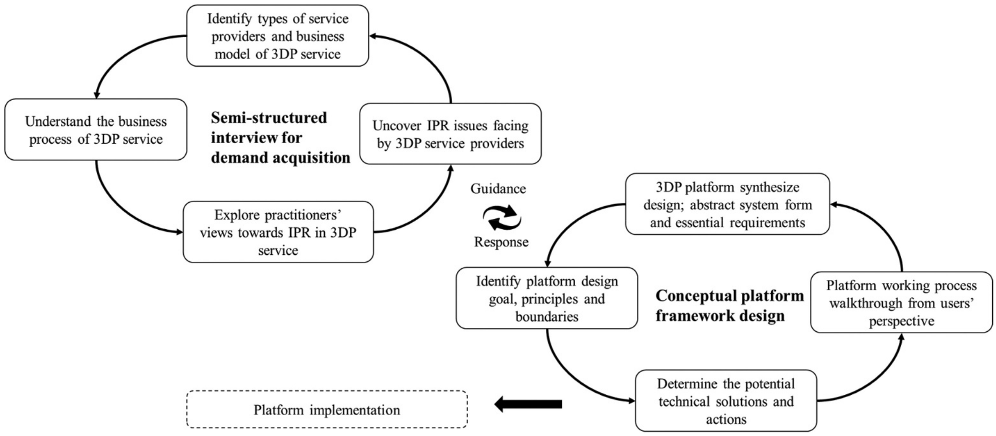

Figure 1. Research framework of the study.

implications of the 3DP intellectual property protection (IPR) platform implementation and application.

In the semi-structural interview, eighteen interviews were conducted. The interviewees are from companies with different 3DP stakeholders, e.g. 3DP manufacturers, distributors of 3DP printers, suppliers of 3DP, the service providers of 3DP, and so forth, which is believed would provide a holistic view of the phenomenon. Further, due to China's significant role in the 3DP industry and, more importantly, the accessibility of firms, companies in different cities in China were selected, i.e. Ningbo, Hunan, Hangzhou, Shanghai, Beijing, Suzhou, and Guangzhou. The information on the interviewed companies is shown in Table 1.

The research team recorded all the interviews with the consent of the interviewees. Then the data was analysed by the schedule suggested by Auerbach and Silverstein (2003), which is shown in the figure below. Manually coding provides more control over data and the opportunity to learn the coding technique. Therefore, the transcription was then analysed manually: (i) the transcription was prepared after each interview; (ii) the 'relevant text' was identified. The transcription was read line by line, and the text relevant to the theme was identified; (iii) texts of 'repeating ideas' were grouped. 'relevant text' identified from the previous step was read, and those repeating ideas were coded into groups. Interviews might use the same or similar words or sentences to express similar ideas; (iv) 'themes' were recognised. Groups of repeating ideas would be further grouped into higher-level themes; and(v) 'themes' were organised into larger and more abstract ideas, such as theoretical constructs. The procedure is illustrated in Figure 2.

3.2. Findings from the interview

The result of the data analysis implied that two essential issues that remained might limit the IP protection of 3DP: **authentication** and **transaction**. Further, the conversations with interviewees also show the business process of how enterprises provide 3D printing services.

Table 1. Information about the companies interviewed.

	Position of interviewee	Location	Business type
Interviewee 1	CEO	Ningbo	3D printer and robot production
Interviewee 2	CEO and CTO	Ningbo	3D printer and 3D maker online community
Interviewee 3	CEO and founder	Ningbo	Foreign 3D printer brand distributor
Interviewee 4	Founder and Chairman	Hunan	One stop solution provider of industrial grade materials
Interviewee 5	Deputy of General Manager	Ningbo	3D printing service provider
Interviewee 6	Marketing Manager	Ningbo	3D printing service provider
Interviewee 7	CEO and founder	Hangzhou	Cloud printer service provider
Interviewee 8	CEO and founder	Hangzhou	3D scanning service provider and 3D scanner distributor
Interviewee 9	CEO and founder	Ningbo	3D printing software provider, IP application service agent
Interviewee 10	Manager	Shanghai	Online 3D printing store and 3D printing service provider for marine industry
Interviewee 11	Manager	Shanghai	3D printing in metal service provider
Interviewee 12	Sales Manager	Shanghai	3D printer part: optical engine design and manufacturing
Interviewee 13	CEO	Beijing	One stop advanced manufacturing solution provider
Interviewee 14	CEO and founder	Beijing	3D design and scanning
Interviewee 15	Marketing director	Beijing	3D printing sevice provider
Interviewee 16	CTO	Beijing	3D design online community
Interviewee 17	Sales director	Shanghai	3D printing solution provider
Interviewee 18	CEO and founder	Guangzhou	3D printer production

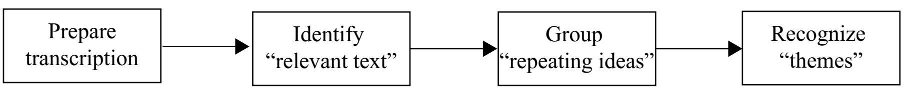

Figure 2. Data analysis process.

3.2.1. Authentication

The needs for authentication. Some practitioners do not consider IP in the 3DP industry. For instance, some interviewees only consider IP mainly to show investors to obtain funding. Other practitioners think that IP protection might limit the development of the 3DP industry, as it would limit the designers' scope of innovation. One interviewee mentioned that 'the 3DP market is not big enough, so the value of technology is not highlighted … 3D printing industry proliferates in the future, and the technology can be popularised, our patents will become valuable' (interviewee 2).

Even though some practitioners are aware of the issues associated with IP, they do not prefer to apply for different reasons, such as the amount of time it takes and the cost. One interviewee mentioned, 'Applying one intellectual property would take two years at least, and it might be longer. This is too long for us' (interviewee 1). Another interviewee held a similar view, saying, 'It takes a too long time to apply for a patent. Also, technologies are updating too fast. They might be updated or eliminated till we get the patent' (interviewee 2).

From a technological standpoint, IP protection for 3D digital designs is more complicated than for physical items. One of the reasons is that it is difficult to trace the original source. There is a limited approach to identifying the originality of a printing file or physical items. Furthermore, as interview 8 said,

> we are trying to put QR code on the 3DP item to protect the license, but the current formats are different, one is 2D, and the other is 3D, which makes it hard to combine the QR code and the physical item for protection

3.2.2. Transaction

The needs of transaction. There is an imbalance of power between 3DP service providers and the customers who need printing services. As interviewee 1 mentioned, providers do not ask customers whether the latter owns the IP of the provided 3DP designs, as the customer might leave and seek a different service provider to print.

Some practitioners we interviewed indeed realise the importance of IP in 3D digital designs. However, they do not know where to buy those rights. For instance, interviewee 2 said, 'We once wanted to buy a patent. However, we could not find any channel to do so'. Platforms offering transaction services do exist. Even so, the issue of IP infringement cannot be avoided for diverse reasons. First, there is the cost of officially using the IP provided by this kind of platform. Individuals may prefer not to pay: 'some of our customers want to use a patent instead of buying one because the cost of purchasing is usually high' (interview 2). Thus, they choose to use open sources, which might not be officially obtained. The easy accessibility of digital designs today encourages individuals to download, customise, and print any items they want without any payment to the owner of the original content. Second, although individuals may pay to use digital designs for printing from such a platform, they may sell a physical item printed using the digital design they buy and make money from it. It is difficult for the original designer or platform to realise or trace this. Furthermore, as mentioned by almost every interviewee, there is little to no punishment or very low punishment for IP infringement (e.g. interviewees 4 and 5).

Most interviewees understand the issue of IP protection for 3D digital designs. However, such protection is commonly perceived as either unnecessary at the current stage or challenging to obtain. This difficulty mainly stems from authentication and transaction. Authentication might be difficult due to technical constraints. At the same time, the transaction might be difficult due to the lack of awareness of IP protection and the imbalance of power between 3DP service providers and customers who need printing services. Accordingly, we propose a conceptual platform that provides authentication and transaction functions for 3DP designs and items, which we believe addresses the issues identified by the interviewees. This aligns with the suggestions provided in other studies, such as the research conducted by Chan et al. (2018).

3.2.3. Working process of 3D printing service

Though there were different types of enterprises which provide printing services, e.g. 3D printer distributors and 3D printing service providers, we name all offering such services' 3D printing service provider'. Moreover, we realised that different kinds of customers with different characteristics exist. For instance, some are companies, while some are individuals who might or might not be designers. We categorise them into '3D physical model consumers', as they all need physical items printed.

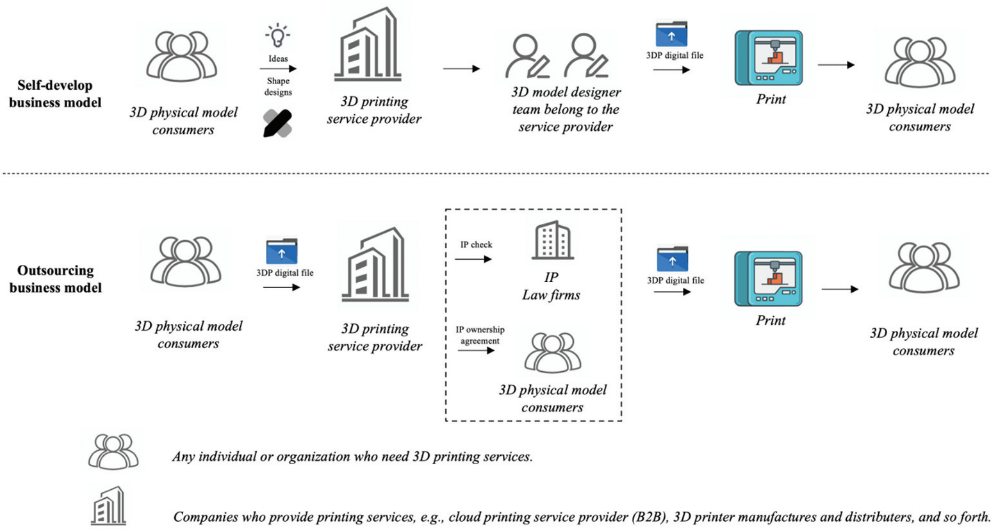

Figure 3. Working process of 3D printing service.

From the investigation, two kinds of business models for 3D printing services were identified: the self-develop business model and the outsourcing business model (Figure 3). The former model starts with the requests from the 3D physical model consumer (hereafter, 'consumer'). The consumer would share the ideas or the outside designs with the 3D printing service provider (hereafter, 'service provider'). After that, the designer of the service provider would design the printing file accordingly, which would be later printed. The physical item would be delivered to the consumer at last. In general, the interviewees think there is a low risk of IPR. However, there is another kind of business model that differs from the former one, as the consumer provides the original printing file. As aforementioned, different enterprises have diverse opinions and behaviour towards IPR. Among the companies that care about IP, one approach for them to check the IPR issue is to hire IP law firms to check the IP source. However, this is only available for designs with officially registered patents, not for all the designs. Another approach is to sign an IP ownership statement with the consumers who provide the file, which is mainly considered to help service providers to protect themselves. Even so, the number of companies who do care about the issues related to IPR is rare.

4. Implementation platform framework

Advanced deposition technologies and digital platforms can effectively protect the IP of 3D digital designs. In previous literature and practical experience, the common practice has been storing information about IP in a private storage system (centralised storage structure) (Benisi, Aminian, and Javadi 2020; Fowler 2002). While this solution ensures the security of the information, it inhibits the sharing of information; it can only be shared on a small scale. Furthermore, if the data storage device is damaged, the corresponding digital designs' IP information is lost or difficult to retrieve (Sinsel, Riemke, and Hoffmann 2020; Watson and Dehghantanha 2016). As a result, the industry and academia are increasingly examining the advantages of blockchain-distributed ledgers for storing IP information and using blockchain as an information storage method to maximise information sharing and usage. Therefore, we design a 3DP digital model sovereign information storage system based on a blockchain architecture. We then connect end-users through the digital platform to generate a scale effect, thus providing a complete chain of digital designs' IP information storage and enquiry, as well as 3D digital design resource transaction services.

4.1. Design principle

According to the literature review and preliminary empirical research results, we will produce a 3DP authentication service platform based on an authentication algorithm and technology supported by the patented watermarking encryption algorithm[1] and 3DP model visual identity technology. The construction of the framework will obey the following design principles, which were also addressed by Böhme et al. (2015) and Søgaard (2021).

4.1.1. Scalability and openness principle

The system's design takes full account of current user needs in 3DP and identification while considering long-term needs regarding future business development, leaving ample possibilities for upgrading and expansion. Users can not only authenticate 3D digital models through their own platform, but also provide third-party 3DP service providers with an authentication query interface to provide commercial services. There is ample scope for expanding 3DP authentication services and system scale.

4.1.2. Security principle

The system's security is strengthened to ensure the long-term stability and reliable operation of the system from various aspects, such as system security, data security, and network transmission security. The system is designed with strict security and confidentiality to ensure that the internal 3DP sovereign information and digital design information are not stolen, making full use of the network-level, database-level, document-level, and domain-level security and confidentiality mechanisms of the development tools and blockchain architecture to achieve data encryption. It also uses the features of the blockchain distributed ledger to store the digital information related to the 3D models in a distributed manner, guaranteeing tamper-proof data quantity, conformity and integrability (Szabo, Ternai, and Fodor 2022).

4.1.3. Manageability principle

The system should have good manageability so that system administrators can easily and aptly grasp information such as transmission system topology, algorithm errors, user transaction system failures, etc., and configure and adjust the encryption and forensic system to ensure that the system functions well.

4.1.4. Economical and practical principle

This principle involves making full use of modern, advanced mainstream information technology; introducing and developing technically reliable and stable hardware platforms; building good architecture, system interfaces, information processing technology methods, and system operation mechanisms; and ensuring that the system well adaptable, highly advanced, and has a long life cycle. It also considers economy and practicality, makes full use of and protects the existing resources of the system, and improves resource utilisation.

4.2. System architecture

Each 3DP participant (i.e. designers, 3DP manufacturers, legal regulators and the platform) works together to build an alliance blockchain to form an ecosystem. In this alliance blockchain, parties can share and trace information transparently and reliably (Zheng et al. 2021). Other types of services can be developed based on it, such as 3D digital design trading services. Thus, the blockchain-enabled platform framework will consist of five layers: Application and presentation layer, Contract layer, Consensus layer, Network (business) layer, and Data storage layer for supporting the whole business process (Li, Wang, and Zhang 2021; Lim, Xiong, and Lei 2020). The initial design of the platform framework and architecture is shown in Figure 4.

- **Application and presentation layer**: The external access layer supports front-end services application, which provides a user-friendly interface for end-users to upload 3D laser scanning files and encrypt and authenticate the sovereign information of 3D digital designs. Web and smartphone portals or third-party website API interfaces can access it, providing a complete set of 3DP authentication, 3D digital designs transaction data storage, users' management and system management for users or third-party service providers.
- **Contract layer**: The layer envelops different 3DP encryption algorithms and smart contract mechanisms. The uploaded files can be encrypted and authenticated through a self-developed 3DP watermarking algorithm, a visual-recognition algorithm, and document-processing algorithms. Through the layer, the user's 3D digital design will be altered by invoking the encryption algorithm and returning the encrypted file to the user and recording the relevant sovereignty information. The computational recognition algorithm will perform a computational visual scan of the 3D digital design to extract the relevant cryptographic information. Moreover, by analysing business logic, the collected cryptographic data and business subject data domains will be streamlined and standardised in this layer. Then, the distributed smart contract needs to support the automated trading of IPRs digitally designed by 3DP, recording the results of transactions and automatic settlement. Therefore, the smart contract equips three functions: data model function, transaction function, and information query function to meet different application scenarios: (1) 3D digital design IPR data function. Insert 3DP digital model IP fields (including unique ID, expiry time, transaction time and owner ID, etc.) and transaction information (payment information, transaction type, pricing type, etc.) for supporting the platform transactions business. (2) The transaction function will support the transaction service of the 3D digital design. When the user selects the 3D digital design with the expected price, the system stores the user's transaction requirements in the smart contract's structure. When the two parties have determined the subject of the transaction and the price, they enter the transaction process. Meanwhile, suppose

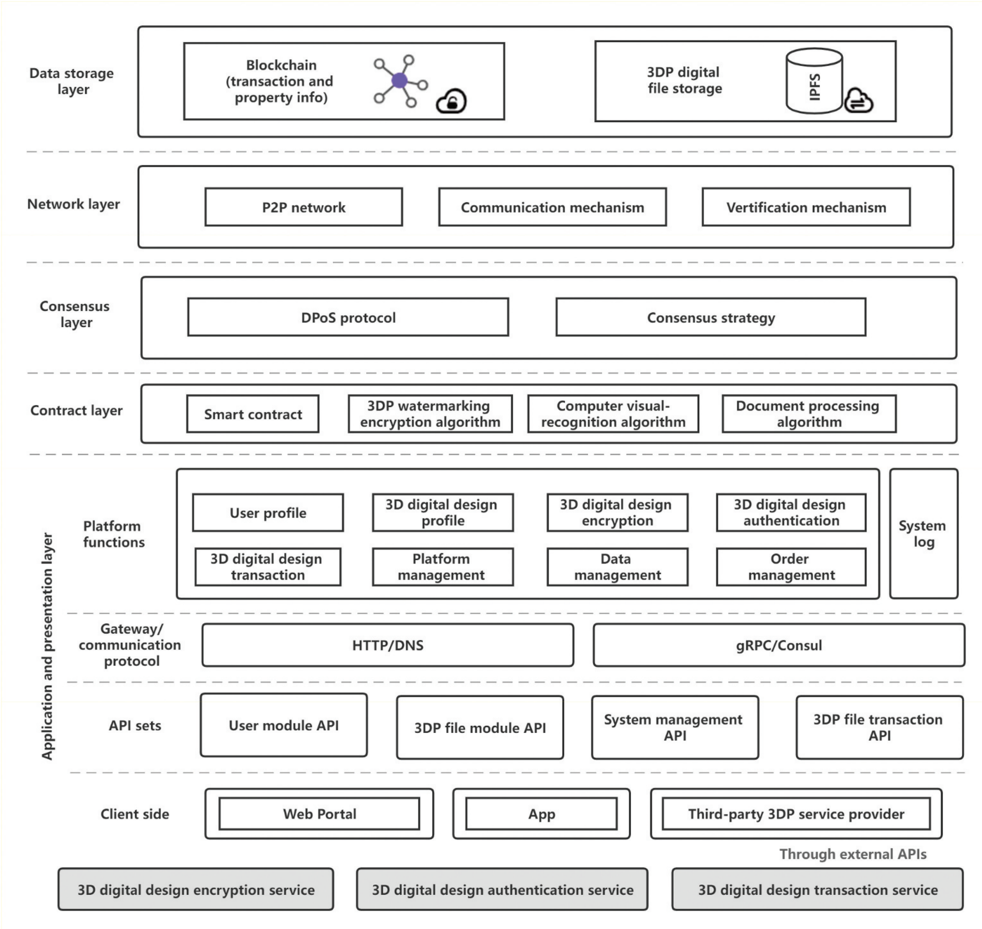

Figure 4. The platform architecture.

the property of 3D digital design has been changed or expired (each property has settled a certain holding duration). In that case, the updated information will be synchronised with the various nodes of the supervisory and arbitration authorities on the alliance chain. Then, the corresponding file on the IPFS will be amended or deleted. (3) Information query function. Users can call the function of querying the 3D digital design IP information stored in the database, or they can call the function of returning the transaction information stored in the smart contract through the blockchain account address.

- **Consensus layer**: When each node agrees and confirms the authenticity of that information, the ledger indicates consensus at that point. Blockchain networks use different consensus algorithms to reach a consensus. A consensus algorithm is a set of rules and conditions that maintain system safety, decentralisation, and consistency (Song et al. 2021). This blockchain consensus algorithm is mainly adopted in alliance blockchain, where only licenced institutions have access and storage rights to the ledger (Lim et al. 2021). In this way of accessing and managing transactions, a ledger that requires permission introduces some access control. Thus, the trustworthiness of each node is high, so there is no need to use the Proof of Work (PoW) mechanism, which requires a lot of time and computing power for each node to compete to reach a consensus (Rebello et al. 2021). In contrast, the Delegated Proof of Stake (DPoS) mechanism uses all nodes to vote for a super node to generate and verify the new blocks, which requires very little computing time and consumption to ensure the blockchain system can function properly (Ferdous, Chowdhury, and Hoque 2021). Therefore, the DPoS consensus algorithm is more concise and efficient, and is more suitable as the consensus algorithm of the system.

- **Network (business) layer**: The network layer acts as a working mechanism layer that allows the governing parties to jointly participate in updating, disseminating, generating and validating blocks. The P2P network consists of four participants: the designer, the 3DP manufacturer, the legal regulator and the platform party. The data from every node is also transferred and exchanged based on data communication and validation mechanisms.
- **Data storage layer**: The corresponding 3D digital design will be stored in Inter Planetary File System (IPFS) for the front-end to query and authenticate. The IPFS provides a network transport protocol for creating persistent and distributed storage and sharing of 3D digital design, and it is a peer-to-peer hypermedia distribution protocol for content addressing (Kumar et al. 2021). The nodes in an IPFS network form a distributed file system. Meanwhile, the digital sovereignty information of the 3D digital design will be passed into the blockchain structure as a digital fingerprint and index information (Zhu et al. 2021). The blockchain architecture primarily provides decentralised distributed blocks that contain all 3D sovereign information entries. These sovereign information entries are recorded in the order in which they appear and form hash blocks. Thus, the database is a hash blockchain of transactions, where each block points to a previous block in the chain. The distributed ledger is shared across the entire network of the blockchain, which means that each node has a copy of the ledger so that each node can independently validate the sovereign information of the 3D digital design. The block header consists of the parent hash, state root, property root, time-stamp, block size, and transaction root. It will support audit and governance services on the blockchains to keep the data integrity and accuracy. The platform database relationship can be modelled in figure 5.

4.3. Platform use case

This study leverages the advantages of platform-based, systematic, and integrated blockchain architecture to provide a convenient and reliable 3DP encryption and authentication platform for commercial end customers. The services supported by the platform and technical architecture include, but are not limited to, 3D digital designs watermark encryption service, 3DP finished product attribution and authentication service, 3DP data storage service, and 3D digital design file transaction service. The overall business and system process flow is shown in Figures 6 and 7.

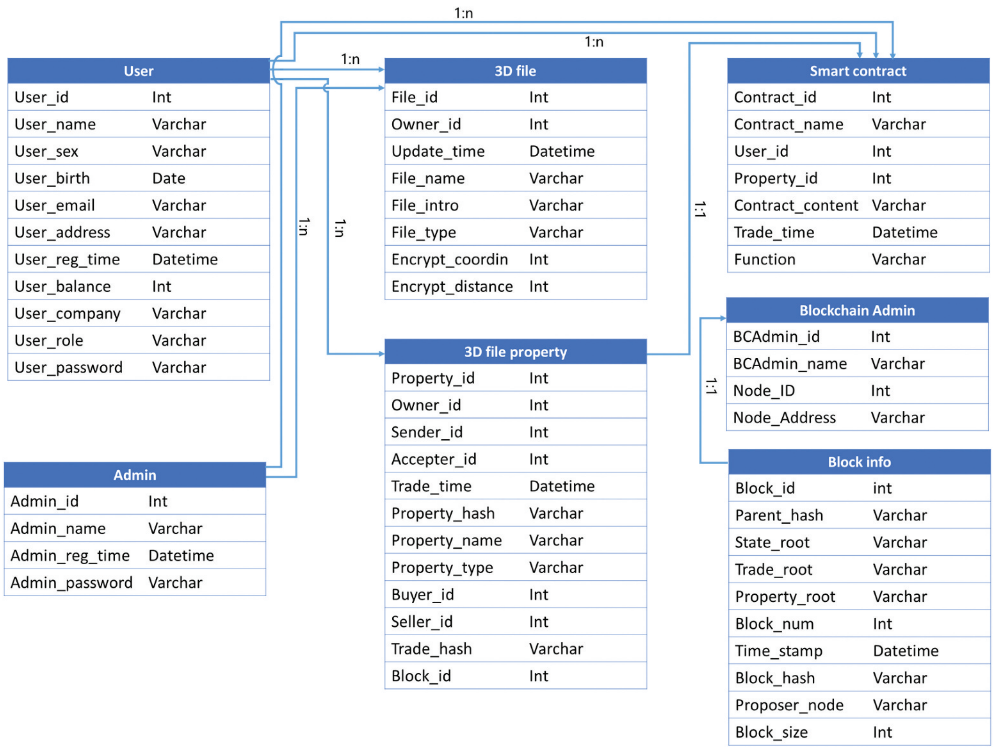

Figure 5. System database entity relationship diagram (ERD) modelling.

4.3.1. End-user 3D digital design encryption business process

The end-user (generally the 3D physical model consumers or designers) either uploads the 3D digital design (stereolithography: STL format or Object: OBJ format) to the platform website on their own or uploads a 3D digital file through a third-party 3DP service provider website (API access). The file is transferred to the standard algorithm layer server pending business operations. At the same time, the 3DP watermark encryption technology algorithm is invoked to write the encryption algorithm to the corresponding coordinate position of the file, while the original 3D digital asset and the sovereignty information of the written password are saved in the backend cloud blockchain storage medium as a digital fingerprint for later authentication verification. The encrypted 3D digital asset file and certification are returned to the end-user through the website or API, completing the entire encryption business service process.

4.3.2. End-user authentication business process

The end-user scans the 3D printed solid model through a laser scanning terminal device (e.g. a laser scanning device equipped with a mobile end), generates a scan point cloud file, and uploads the 3D solid model scan file to the platform website (or through a third-party 3DP service provider website) through the platform APP. The scanned point cloud file is passed to the server for business operation, and a computational visual recognition algorithm is invoked. Based on the 3D digital asset watermark encryption algorithm, the encrypted string and the altered coordinate information are accurately identified. The

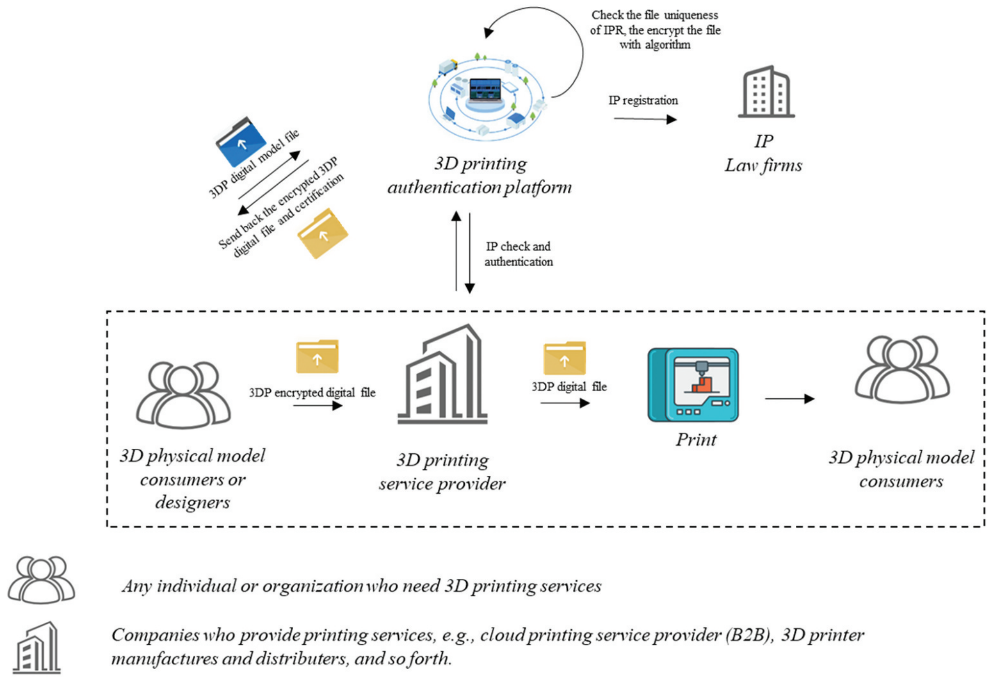

Figure 6. The business process flow of 3D print working process with authentication platform.

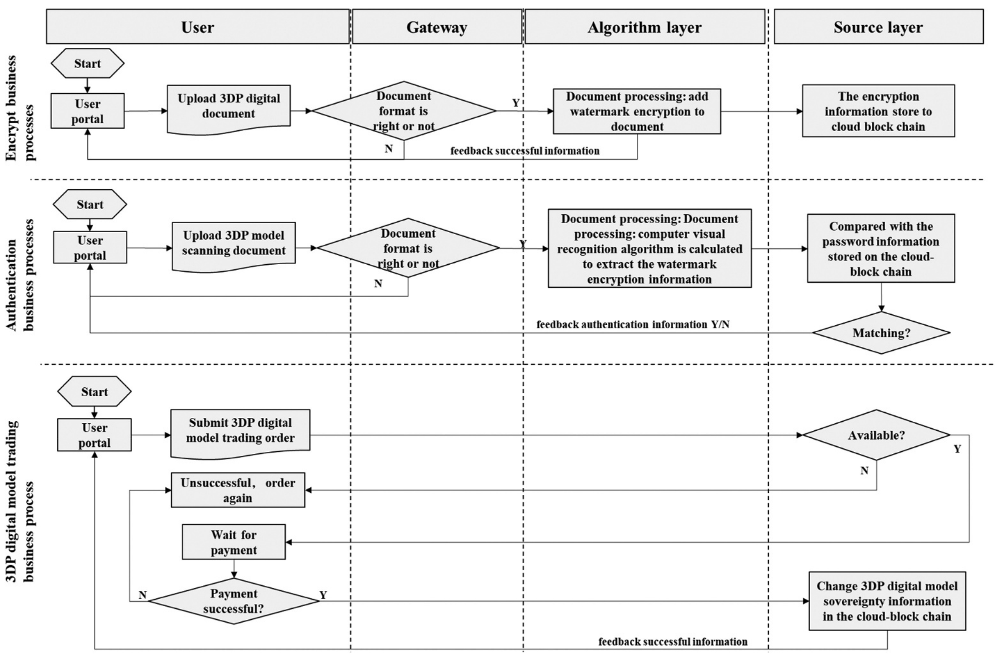

Figure 7. The system process flow of the platform.

modified string is used as the primary key to match with the encrypted data in the blockchain storage media in the backend cloud. The matching result is returned to the end-user (or the third-party 3DP service provider) to complete the business process (If the authentication is successful, information including the attribution and creation time of the 3D digital asset is returned).

4.3.3. 3D digital asset transaction business process

When its scale is taken advantage of, the platform can reach more 3DP digital design originators who are aware of IP protection. The 3DP digital design stored through the above-encrypted business process is selected by users to be stored in the platform's 3D model data pool for other users to view, purchase, download, and share. Thus, this can form a more complete 3DP digital design database, allowing users to visualise 3DP printed digital design through AR/VR technology to enrich their shopping experiences. In the event of a purchase or a change of ownership of a 3D digital design, the system will automatically update the relevant ownership information in the cloud blockchain.

5. Discussion and implications

Prior studies have identified that 3DP raised social concerns regarding data leakage and IP infringement (Chan et al. 2018; Ivanov, Dolgui, and Sokolov 2019). With the help of emerging blockchain technology, which can provide an ideal solution to tackle the data reliability of both the authentication process and transmission process, this research extends the study conducted by Chan et al. (2018) and proposes the conceptual framework of the suggested licencing platform for 3DP digital assets' IP protection with the dual-circle information system design method.

To map back to the literature gaps, this paper makes several original conceptual contributions. First, we conducted interviews and research to gain insight into the 3DP business working process, pain points and potential solutions for 3DP-IP protection in the industry. We can state that the current challenges create a need for a channel to protect 3DP digital assets' IP sovereignty. Second, to better combine the potential IP protection solution to address the 3DP-IP protection issue, we create an encryption, authentication, and transaction platform for 3DP digital assets, combining the advantages of patented watermarking technology, digital platforms, and blockchain technology. There proposes the interactive working process of these techniques.

Furthermore, several innovative supporting algorithms are developed in the conceptual framework to provide a complete authentication solution. Third, to fill the gap where the platform's role is unclear for 3DP-IP protection, this paper takes advantage of platformisation and blockchain structure to provide a convenient and reliable 3D design encryption authentication platform for commercial end customers. Meanwhile, the business mechanisms of the system and users' data flow are further explained, and then the functional role of the platform is fully identified in this study.

5.1. Theoretical implications

This study aims to solve the pain points of authentication and IP protection faced by users in the protection of 3DP digital assets, which has several theoretical implications.

According to the users' requirements, the study designs the system architecture of the blockchain-enabled platform and workflow for the joint blockchain technology, 3D watermarking cryptographic algorithm technology and platform-based technology. The platform proposed leverages blockchain technology characteristics like distributed ledger, tamper-proof and consensus algorithms, and sovereign information (e.g. encrypted watermarking and ownership) of 3DP digital assets is recorded and shared across the entire network, further securely stored and flexibly accessed. Thus, it allows the protection of the IP of 3DP digital assets. In this case, we derive the corresponding design principles for IP protection-related information systems, which completes the theory of IP information system design science.

We design the relational model of the corresponding database and the logic of data transfer for the storage and interaction of the many different data formats (i.e. structured and unstructured) on the platform, in conjunction with blockchain and watermarking technologies. The primary technology of this research lies in 3D design document compilation technology and computational visual recognition technology, which are the extension of current 3DP watermark encryption algorithm patents. When the former is applied, the 3D design file (STL, OBJ, or BFB file format in CAD software) uploaded by the user is edited and written with an encrypted watermark, and the encrypted file is returned to the user. The user can scan the physical 3D item to obtain the corresponding 3D print scan file. The encrypted watermark string is automatically identified and extracted from the scanned file through computational vision technology algorithms for comparison and authentication in the backend database. Thus, this process can protect the 3D digital designs and provide anti-counterfeiting identification for the printed physical model. The platform can also utilise the characteristics of data interactive authentication and distributed data management on different nodes enabled by blockchain technology to ensure the integrity and consistency of authentication data. Moreover, with an integrated platform, users can enjoy an easy-to-use and trustworthy channel to protect their 3DP digital assets' IP. The data-related process design can be implemented in other similar IP protection platforms with a multi-type data source.

5.2. Practical implications

Behind the growth of the service and consumer 3D printing industry, model piracy and intellectual property issues have become increasingly severe. When the price of 3D printers and accompanying laser scanners became commonplace, the problem of cheap knock-offs of goods could quickly proliferate. Meanwhile, 3D digital design is characterised by ease of co-creation and sharing, and the strength relies on the Internet's openness, so the problem of intellectual property rights in the 3D printing industry is becoming increasingly apparent. The platform proposed by the study will provide an integrated ecological environment for the encryption, authentication, trading and storage of 3D digital models, filling the gap in the market.

The platform's encryption business is aimed at users who are mainly companies, teams and individual designers. Designers can watermark and encrypt their original digital models online. Their 3D digital design files and physical model encryption information will be stored in the platform blockchain, realising a 'hard-bound' relationship between the physical model and the encryption information, and the encryption information cannot be tampered with. This cost-effective encryption method is conducive to the motivation of designers and the sustainable development of the 3D printing design industry.

The platform's 3D digital design database and trading platform, relying on blockchain and encryption technology, allows the trading of 3D digital design and the transfer of intellectual property rights to be fully secured. Designers have a more secure environment to create their work without struggling to find sales channels. For 3D digital design consumers, the platform enriches digital models' trading and purchasing channels, builds a platform for exchanging works and potentially promotes the upgrading of 3D design services in the industry.

6. Conclusion and limitations

By constructing such a conceptual framework for a blockchain-enabled platform, we explored the unique effect of the value proposition of blockchain technology on the implementation of IP protection. We discussed the working mechanism of a blockchain-based 3DP digital assets' IP authentication and transaction platform.

The paper shows how 3DP companies can benefit from using blockchain to protect their 3DP digital assets' IP and how an industrial 3DP digital assets' IP system can be built and secured. Based on patented 3DP watermarking technology, the conceptual framework proposed several supporting technologies such as 3DP digital asset encryption algorithm compilation technology, 3DP entity computing visual recognition technology, and blockchain cloud storage technology. It integrated the IP authentication process into the business flow of a 3DP service platform.

Our results show that, with the help of blockchain technology, a platform integrated with 3D design watermark encryption service, 3DP finished product attribution authentication service, 3DP data storage service, and 3DP digital asset design file transaction service can promote 3DP digital assets' IP protection in ways that are user-friendly and accurate. In addition, the proposed platform will accelerate the implementation and expansion of authentication technology application scenarios for various objectives, and thus may tap potential markets, promote the development of service quality standards, explore multiple business models based on its core authentication service, and help promote the standardised development of the 3DP industry and the process of international digital assets' IP protection.

Due to its conceptual nature, this study has several limitations. First, we did not consider the interface protocol between the blockchain of the proposed platform and existing 3DP-related systems and applications. Second, the study lacks a more fundamental theoretical lens for the platformisation and operation of the proposed system. Besides, the complementary business model and legal supervision are still in a defining stage. Future studies can further explore new avenues such as the benefit consensus mechanism among different stakeholders, the combination mechanism of 3DP blockchain smart contracts and manual auditing – due to the labour will still be needed for reviewing and confirming the 3D design's originality, the diffusion of such 3DP authentication platforms and the intervention of the relevant legal and regulatory authorities. Moreover, the practical application of the proposed platform in the future should integrate the authentication results with the digital model copyright protection alliance and effectively enable the authentication service results to be recognised by authoritative institutions.

Note

1. The 3DP watermarking encryption techniques is patented in China, which number is ZL2017104694528.

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