Non-Fungible Tokens (NFTs) in Additive Manufacturing: A Digital Tool for Enhancing IPR Protection *

Alireza Jaribion[1[0000-0003-1916-1309]], Adriaan Knapen[2[0000-0001-6488-6857]], Alberto Xamin[2[0000-0001-9744-4684]], Jan Holmström[1[0000-0002-2596-0337]], and Siavash H. Khajavi[1[0000-0002-5166-4021]]

[1] Department of Industrial Engineering and Management, Aalto University, Finland
[2] Department of Computer Science, Aalto University, Finland
firstname.lastname@aalto.fi

Abstract. Artists, creators, communities, and gamers have expressed substantial interest in non-fungible tokens (NFTs). However, scarce research has been conducted on applying this blockchain-based technology for industrial purposes. This paper develops a web application to use NFT technology for digital spare parts using digital manufacturing techniques, such as additive manufacturing. The research was conducted in collaboration with a deep-technology company using a physical product. This digital tool enabled the company to create the NFT of the products' digital three-dimensional (3D) designs and facilitate the sale of the parts on the NFT marketplace while enhancing the design's intellectual property rights protection due to the traceability of the NFTs on the blockchain. Action design research is used to describe the process of developing the NFT-based digital tool.

Keywords: Non-fungible token (NFT) · Additive manufacturing · Intellectual property rights (IPR)

1 Design of the Artifact

Through a rapid prototyping effort within the context of an industry–academia collaboration project, we present a digital tool for original equipment manufacturers (OEMs) to assist with protecting intellectual property rights (IPR) for the digital designs of spare parts and increasing the control over the additive manufacturing (AM) service chain and end customers. Although the OEM has not yet implemented this prototype, it contains practical and theoretical insights from the perspective of design science [1, 2]. The practical relevance of this prototype is that it has the potential to help digital manufacturing (DM) technologies

* Supported in part by the EIT Digital and Academy of Finland Projects Digital Twin for Safety under Project 682032-T30805 and in part by the Direct Operations under Grant 323831.

overcome IPR barriers to enter the mainstream manufacturing realm, supporting OEMs to preserve IPR in sharing spare part 3D designs with AM service providers or end customers. By searching for a solution to this practical design problem [1](how OEMs using DM service providers can protect their IPR), we investigate the theoretical problem of facilitating decentralized manufacturing through AM technology while maintaining a competitive advantage using digitally traceable IPR.

During three months of close collaboration, a deep-tech startup, information technology (IT) service management company, and university developed the proposed digital tool, which can be characterized as an ensemble artifact [2], supporting the required technical rigor and practical relevance. Accordingly, this arrangement perfectly aligns with an action design research (ADR) project based on design science principles [2]. According to the ADR methodology stages, the proposed digital tool and its design process are described in the following sections [2].

1.1 Problem Formulation

Regarding the problem formulation, industry–academia collaboration projects include ADR principles. At the intersection of AM technology and the competitive advantages of the deep-tech company as an industry project partner, the intention was to develop a prototype to address IPR issues as a class of problems in the DM domain. Therefore, the proposed digital tool was practice inspired [2]. The university is an academic partner; thus, researchers collaborate with technicians to solve the problem considering their theoretical knowledge and background, which results in a theory-ingrained artifact [2]. In this case, the problem is how to assist OEMs in IPR protection regarding three-dimensional (3D) design sharing with third-party AM service providers.

Spare parts operations (SPO) are critical for every OEM because they significantly influence customer satisfaction. Moreover, a successful SPO can provide a high level of profitability for the OEM because the profit margins for spare parts are an order of magnitude higher than the original equipment parts [3].

Traditionally, companies rely on physical spare parts stored in inventories manufactured in-house or by third-party manufacturing service providers with strategic agreements with the OEMs. More recently, DM technologies (e.g., AM) that can manufacture parts from a 3D design file have been used by some OEMs for various components, such as fuel injectors in the aviation industry [4]. The spare parts in these cases can be manufactured as needed by third-party service providers. However, the concern regarding 3D design sharing with third-party service providers has limited the full potential of DM technologies, specifically AM. Consequently, companies rely on AM technology to manufacture these parts "to-stock" and in-house to protect their competitive design advantage and prevent counterfeiting. Therefore, investigating methods to assist OEMs in overcoming this barrier and facilitating AM is crucial.

1.2 Building, Intervention, and Evaluation

The problem owners (deep-tech company representatives) met weekly throughout the project with the researchers and technical solution developers (software engineers from the IT service management company), resulting in several iterative artifact development cycles. The prototype originated from the concept of blockchain technology, more precisely NFTs.

An NFT is a digital asset including "a non-interchangeable unit of data stored on a blockchain," which is "a form of digital ledger that can be traded," frequently online with cryptocurrency [5]. The NFTs are uniquely identifiable, and the creator can easily prove their existence and ownership via a unique digital certificate [5]. They represent real-world objects, such as art, collectibles, music, in-game items, videos, and some versions of 3D files [5]. The NFTs are a promising solution for IPR protection due to their "convenient interoperability, full-history tradability, and deep liquidity" [5].

The industrial partner's problem was twofold. First, the company needed to keep the industrial design of the sensor enclosure guarded against third-party exploitation and counterfeiting because of signal noise barriers they created and smart distancing between the novel ultraviolet sensor and the circuit board. Second, the company needed to provide the customized 3D design to clients and facilitate the sale of the sensor package without committing to in-house production and allowing the use of third-party AM service providers.

Using NFTs, we introduced an intervention into the traditional design-sharing process to assist with protecting 3D design IPR while unlocking the possibility to take full advantage of AM capabilities, including decentralized production (Fig. 1). The prototype we present in this paper was created by combining Web 3.0 technology and robotic process automation (RPA) to facilitate minting NFTs. We used the OpenSea platform for NFTs, which currently is the largest NFT trading marketplace by turnover [5].

The prototype was created in two phases. First, the development efforts were focused on automating the process of NFT minting on the OpenSea platform. Since the OpenSea platform lacks publicly available support for direct machine-to-machine interaction with their platform, we applied RPA technology, which enables the automatic execution of workflows through user interfaces originally designed for human interaction. In the prototype, the RPA solution controls a web browser window and directly interacts with the OpenSea website, automatically completing web forms and collecting data from the OpenSea website. With the RPA process successfully implemented and thoroughly tested in the second phase, the development efforts turned to creating a web-based user interface. The web interface simplifies the use of the RPA solution. The digital tool consists of a user-facing front-end, implemented as a single page application and back-end running of the RPA process. The front-end was implemented using a React-based framework, whereas the back-end runs on Node.js.

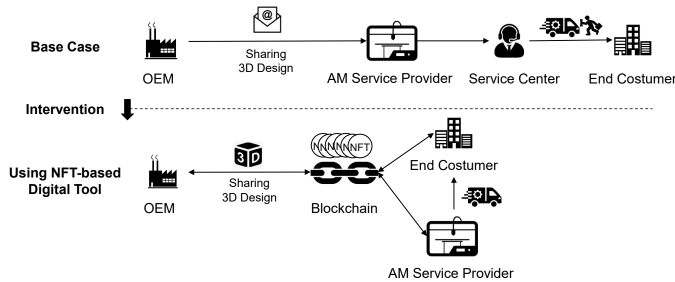

Fig. 1. Traditional base case vs. using the NFT-based digital tool.

1.3 Reflection and Learning

The weekly meetings during the project established alignment among all partners and facilitated creative thinking. Problem owners provided constructive feedback and insightful reflections on the emerging ideas for continuous improvement. Moreover, several days of intense collaboration between all project partners in "working together campaigns" led to the reciprocal shaping of an authentic prototype with concurrent evaluation and mutual learning for problem owners, software engineers, and researchers [2]. The problem owner, the deep- tech company, learned innovation by combination; by adapting technologies from other fields (in this case, NFT enabled by Web 3.0), they can innovate and address problems in their own context. Conversely, researchers learned about the business challenges of a deep-tech company that aims to adopt a decentralized manufacturing technology, in this case, AM, and protect its competitive advantage—a real-world exercise in Porter's five forces [9].

1.4 Formalization of Learning

In the fourth stage of ADR, we describe the implementation process of the digital tool, leading to learning and design principles. In Fig. 2, the first image presents the landing page of the web application that the company can use to upload their 3D model of the spare part. In the second step, the part name, 3D design file, and representative image are uploaded to the web application. In the third step, the 3D design is minted on the NFT platform, and the link to the minted part is provided to the company. The fourth step presents the minted part on the NFT marketplace (OpenSea).

Based on the three levels of learning generalization in ADR projects [2], we formalize learning as follows. First, the problem instance can be generalized to protecting the IPR of digital designs by OEMs adopting DM technologies, such as AM. Second, the solution instance can be generalized as an NFT-based digital tool to trace and monetize any digital asset in production throughout its life cycle. Third, accordingly, based on our experience throughout the project, we state the following design principles (DP):

DP1: The NFT-based digital tools can facilitate the transition of OEMs to DM by protecting their IPR regarding their design's competitive advantage.

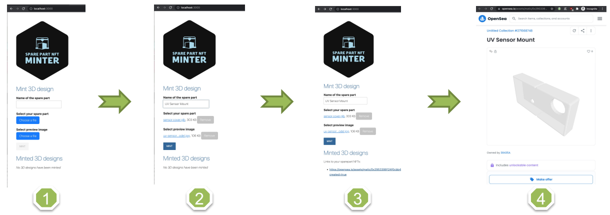

Fig. 2. Four stages of minting 3D designs using the proposed NFT-based digital tool. Prototype link : https://www.youtube.com/watch?v=clxr7EwuvKA

DP2: Companies that have already adopted DM can benefit from NFT-based digital tools and innovations in the Web 3.0 environment, significantly facilitating the monetization and sales of their digitalized spare parts.

2 Significance to Research

Recently, the popularity of NFTs has climbed sharply regarding massive investments and growth in transaction sizes and total value. In 2021, the market cap for NFT transactions surpassed $40bn [7].Although the evolution of the NFT ecosystem is still in its early stages, it is evolving swiftly. Researchers are currently investigating the application of NFTs for healthcare data management, energy infrastructure, management of internet of things devices, value chains of creative industries, and patents and IP management [5]. However, there has been limited but increasing research on the application of NFT in manufacturing. This paper introduces a new application for NFTs in DM, specifically AM. Moreover, although the AM research has been developing solutions for technical problems regarding the design, material, process, and operation of this technology in supply chains, the current field of research has not yet fully addressed issues arising from 3D model design sharing and IP conflicts in the context of decentralized spare part manufacturing [3] [6]. In this paper, we envisage that the NFT-based digital tool can contribute to the resolution of IP issues and the monetization of 3D designs by OEMs.

3 Significance to Practice

Currently, NFTs are used in a few specific fields, including artwork and digital collectibles, the gaming and music industries, and virtual events [5]. The NFT-based digital tool facilitates adding an industrial application in the field of DM to the current narrow spectrum of applications. Moreover, DM technologies, which rely on the production of objects from digital design models, are growing rapidly [8]. In this vein, DM, specifically AM, poses a threat to OEMs concerning IPR. More specifically, spare parts that can be additively manufactured are based on 3D design models susceptible to IP infringement by AM service providers or unauthorized manufacturers. We designed the NFT-based digital tool to combat IP infringement and facilitate sharing 3D designs by OEMs, improving three main criteria governing digital spare parts: availability, cost, and time [6].

4 Evaluation of the Artifact

Currently, the proposed prototype is entering field testing parallel to the finalization of this paper. Based on the deep-tech company's evaluation, NFTs are among the few blockchain-based technological solutions they examined to create trust between the stakeholders while enhancing flexibility and efficiency in the production operations. According to the CEO,

"The prototype allows us to reach a larger customer base and potentially higher sales by enabling us to quickly bring the products from design to the [online] market without IP concerns. This can be translated to a competitive advantage for our company. Moreover, it has the potential to complement and gradually replace the legal frameworks for IP protection in the context of manufacturing."

Furthermore, the deep-tech company noted that the following field improvements are required. First, traditional legal procedures are not up to the task and must catch up with the current digital transformation. Additionally, smart contracts enabled by blockchain technology are not yet equally legally binding as non-disclosure agreements and sales contracts. For the full potential of NFTs, smart contracts should be admissible in court. Second, technologies that can create an interface between the data transfer and production platforms (e.g., AM machines) must be improved. This interface can facilitate transactions between OEMs, end customers, and production facilities. Currently, the data interface between the NFT hosting platform and AM machines is non-existent. Third, the prototype faces a limitation imposed by the NFT minting platforms (e.g., OpenSea) that still do not support a wide range of 3D design file formats, which can easily change as the NFT minting platforms mature.

References

1. Holmström, J., Ketokivi, M., & Hameri, A. P.: Bridging practice and theory: A design science approach. Decision Sciences **40**(1), 65–87 (2009)
2. Sein, M. K., Henfridsson, O., Purao, S., Rossi, M., & Lindgren, R.: Action design research. MIS quarterly, 37–56 (2011)
3. Khajavi, S.H., Salmi, M. and Holmström, J.,: Additive manufacturing as an enabler of digital spare parts. In Managing 3D Printing (pp. 45–60). Palgrave Macmillan, Cham (2020)
4. Khajavi, S.H., Ituarte, I.F., Jaribion, A., An, J., Kai, C.C., Holmstrom, J.: Impact of additive manufacturing on supply chain complexity. In Proceedings of the 53rd Hawaii International Conference on System, Maui, HI, USA, 7–10 January (2020)
5. Wang, Q., Li, R., Wang, Q. and Chen, S.: Non-fungible token (NFT): Overview, evaluation, opportunities and challenges. arXiv preprint arXiv:2105.07447 (2021)
6. Ballardini, R.M., Ituarte, I.F. and Pei, E.: Printing spare parts through additive manufacturing: legal and digital business challenges. Journal of Manufacturing Technology Management (2018)
7. Bloomberg, https://www.bloomberg.com/news/articles/2022-01-06/nft-market-surpassed-40-billion-in-2021-new-estimate-shows. Last accessed 14 March (2022)
8. Gentzsch, W.: Manufacturing is finally ready for digital transformation. MIT Technology Review (2022)
9. Porter, M.E.: The five competitive forces that shape strategy. Harvard business review, 86(1), pp.25–40 (2008)