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# Blockchain Technology Integration with Additive Manufacturing: Analysis of Challenges

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## Abstract

The adoption of Additive Manufacturing technologies is on the rise owing to the benefits that can be gained from the technology, such as environmental sustainability, supply chain responsiveness and mass customization capabilities. These benefits arise mostly due to the digital design nature of the technology which provides immense design freedom. However, these digital designs are also susceptible to cybersecurity risks. To tackle these challenges, researchers are exploring the integration of Blockchain with Additive manufacturing. However, there are challenges and considerations associated with this integration. This study identifies these challenges from existing academic and practitioners' literature and finds the hierarchical and causal relationship between them using fuzzy DEMATEL. This study fills the existing literature gap by finding the solutions to the current debate on the cybersecurity threats associated with Additive manufacturing technologies. The practitioners can use this study to be better prepared and ensure the smooth adoption and implementation of the technology.

## Keywords
Additive manufacturing, Blockchain, Challenges, DEMATEL

## 1. Introduction
In the last decade, the world has witnessed several events that highlight the need for operations and supply chains to be more robust, resilient, and environmentally sustainable. While the COVID-19 pandemic demanded resilient supply chains, the world events caused due to climate crises, demand a circular economy and decarbonization across the supply chain and in all operations. Moreover, with the increasing demand for customized goods, there needs to be a higher focus on resilience, flexibility, and environmental sustainability (Priyadarshini et al., 2023). Though industries and organisations are working hard on these fronts, they have not succeeded in achieving these goals.

Previous researchers have highlighted the importance of Industry 4.0 technologies in the fulfilment of these objectives. Additive manufacturing (AM), also known as 3D printing, is an Industry 4.0 technology that involves a layer-on-layer joining of materials to manufacture a product (ASTM F2792-12, 2012). AM has numerous benefits for the supply chain. AM allows for part consolidation due to its additive nature. This minimises the requirement for tools, jigs, and fixtures (Berman, 2020). Consequently, the weight of the final product is decreased while the strength is enhanced. In addition, through the consolidation of several components, additive manufacturing (AM) contributes to the reduction of supply chain intermediaries. This minimises the complexity of the supply chain and improves the agility of the supply chain. Moreover, this also contributes to reducing the expenses associated with operations (Rinaldi et al., 2021).

However, there are certain risks associated with the technology. The digital nature of the technology poses risks where digital designs can be easily copied and where counterfeit goods can be produced easily. Owners of 3D printers have the option to purchase licenced designs for 3D printing. However, there is a possibility that these owners may print things that are protected by intellectual property (IP) rights without getting the required permissions (Esmaeilian et al., 2019). It is convenient for numerous entities to access, edit, and use an asset when it is shared across a network. Hence there is a need to integrate blockchain technology along with AM. Blockchain technology is a potential basis for establishing a secure communication protocol without the need for a third party. A peer-to-peer decentralised network with a data protection system can be made with this technology. A blockchain possesses the capability to monitor alterations in data and safeguard them without requiring a third-party authentication procedure to start functioning (Vatankhah Barenji et al., 2019).

Despite having immense benefits for AM, the integration of blockchain technology with AM is challenging. This study focuses on identifying these challenges and establishing the hierarchical and causal relationship between them. The discussion of the integration of blockchain with AM to improve the performance of AM is limited in the literature. However, numerous researchers have highlighted the need to harness the potential of Industry 4.0 technologies to improve the performance of 3D printing technologies.

### 1.1 Research Questions

To fill the aforementioned research gaps, this study intends to answer the following research questions:

RQ1: What are the barriers to the implementation of blockchain technology with Additive manufacturing?
RQ2: What is the hierarchical and cause-and-effect relationship between the factors?

To answer the research questions, first, a literature review is conducted and factors are identified. Then, using fuzzy DEMATEL, a multi-criteria decision-making technique. The hierarchical and cause-and-effect relationship is established.

## 2. Literature Review

The first phase includes a pilot search to understand the number of studies being done on the chosen topic. The database used was Scopus. In order to have an exhaustive list of the research papers on the topic, the keywords such as ‘Additive manufacturing’, and ‘Blockchain’ were included in the syntax.

TITLE-ABS-KEY ( ( "Additive manufacturing" OR "3d printing" ) AND ( "Block chain" OR "Blockchain" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) ) AND ( LIMIT-TO ( DOCTYPE , "cr" ) OR LIMIT-TO ( DOCTYPE , "ar" ) OR LIMIT-TO ( DOCTYPE , "re" ) ) AND ( LIMIT-TO ( SUBJAREA , "BUSI" ) OR LIMIT-TO ( SUBJAREA , "DECI" ) OR LIMIT-TO ( SUBJAREA , "SOCI" ) OR LIMIT-TO ( SUBJAREA , "ENGI" ) )

The Boolean search using the said keywords returned a total of 252 documents from SCOPUS. So, the necessary inclusion and exclusion criteria were applied to the search string. The language was restricted to English and Subject areas were limited to ‘Business, Management and Accounting’, ‘Social sciences’, ‘Engineering’ and ‘Decision sciences.’ The document type was limited to ‘articles’, ‘review paper’ and ‘conference paper.’ These changes finally gave us 118 documents from Scopus. After the abstract and full-text screening, 42 papers remained a part of this study. In order to do the analysis, each paper was reviewed and the relevant information pertaining to the research questions was extracted. The PRISMA flow diagram for paper selection criteria has been mentioned in Figure 1.

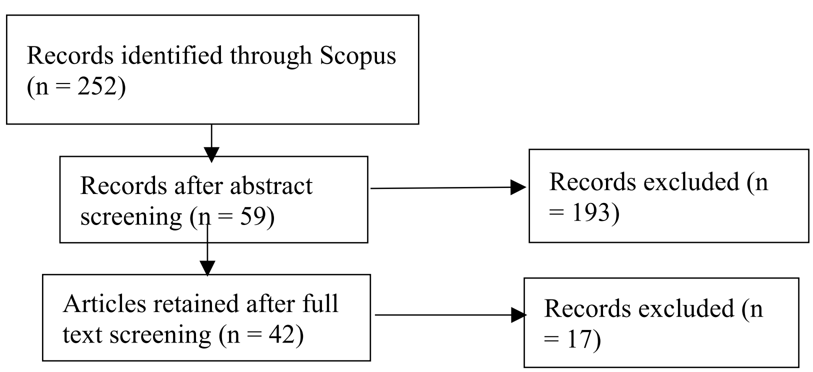


Figure 1. PRISMA framework

Once, the articles were finalized, the authors, read each article to identify the barriers to the integration of blockchain technology with AM. After discussion amongst the researchers, 11 factors were finalized for this study. The factors can be seen in Table 1.

Table 1. The factors

| ID | Barrier | Description | Reference |
|---|---|---|---|
| F1 | Resistance to change | One major barrier to the widespread use of smart contracts is the incapacity of automated contracts to handle uncertainty and change. | Singh and Kumar, 2022; Efthymiuo et al., 2022 |
| F2 | Legal and regulatory compliance | From a legal perspective, there are very few laws and rules governing smart contracts. Obtaining governmental authorization for blockchains and smart contracts may pose a challenge. | Singh and Kumar, 2022; Kar et al., 2019 |
| F3 | User acceptance and trust | Persuading stakeholders to use blockchain technology in additive manufacturing may encounter opposition because of ignorance, mistrust, or aversion to change. There have also been a lot of false use cases and unrealistic assumptions. | Singh and Kumar, 2022; Walthal et al., 2020 |
| F4 | Energy consumption | Decentralised blockchain consensus algorithms typically necessitate substantial amounts of computing power and energy. Certain blockchain networks are known to use a lot of energy, particularly those that employ proof-of-work consensus techniques. From an operational and environmental standpoint, this may be challenging. | Guo et al., 2023; Barenji et al., 2019 |
| F5 | Scalability | Scalability of blockchain technology becomes a critical factor as the amount of data and transactions in additive manufacturing increases. Due to the ever-increasing transaction records stored in blockchain, there is an issue of effectively splitting a large amount of transaction data between the operational level and the enterprise level. | Guo et al., 2023; Rozman et al., 2023 |
| F6 | Privacy protection | The implementation of blockchain technology in smart manufacturing can enhance its security by utilising asymmetric encryption and digital signatures. However, there remains a potential for cyberattacks due to the susceptibility of blockchain systems. | Guo et al., 2023 |
| F7 | Lack of requisite skills | Both AM and blockchain require skill to operate. However, since the technologies are fairly new, finding the apt skills for them is a challenge. | Calle et al., 2019 |
| F8 | System Integration | The integration of the technologies requires changes to existing systems, which is quite complex. Moreover, different organisations might use different blockchain technologies, which makes interoperability, a challenge. | Abdulrahman et al., 2023; Song and Zhu, 2021 |
| F9 | Network throughput | An increased number of miner nodes (computing power) impacts the throughput of the network. Certain blockchain networks may exhibit slower transaction processing times in comparison to conventional databases. Delays in confirming transactions and creating blocks can have a negative influence on the efficiency of the additive manufacturing process in a high-speed manufacturing setting. | Barenji et al., 2019 |
| F10 | Implementation costs | Blockchain integration requires a significant outlay of money including significant upfront costs for development, integration, and maintenance | Kurpjuweit et al., 2021; Singh et al., 2022 |
| F11 | Lack of top-management support | The top management or the decision-makers in an organisation are not aligned to the adoption of novel technologies. Without their support, aligning the entire organisation to the adoption and implementation of novel technologies becomes a challenge. | Kurpjuweit et al., 2021; Rathore et al., 2022 |

## 3. Methods

This study utilized the fuzzy DEMATEL to establish the hierarchical and cause-and-effect relationship between the factors. DEMATEL is an MCDM technique used to analyse the causal relationship between factors. The fuzzy set theory used along with it helps deal with uncertain situations and limited information due to linguistic expressions. Hence, fuzzy DEMATEL helps explain the interdependencies and relationship between the effect group (factors predominantly influenced by other factors) and the cause group (factors mainly influencing other factors) (Mavi and Standing, 2018).

Following are the steps involved in Fuzzy DEMATEL:
*Step 1:* Establishing a five-point fuzzy linguistic scale for pairwise comparison as provided in the Table 2

Table 2. Fuzzy linguistic scale

| Linguistic variable | Triangular fuzzy number |
|---|---|
| No influence (No) | (0, 0, 0.25) |
| Very low influence (VL) | (0, 0.25, 0.5) |
| Low influence (L) | (0.25, 0.5, 0.75) |
| High influence (H) | (0.5, 0.75, 1) |
| Very high influence (VH) | (0.75, 1, 1) |

*Step 2*: Generating the direct relationship matrix.
For this purpose, industry experts were identified who were willing to participate in the study. A total of 7 experts were identified for this study through a combination of purposive and snowball sampling. These experts had knowledge of both blockchain as well as Additive manufacturing technologies. All of them had greater than 5 years of experience and hailed from the automotive, and spare parts sectors. These experts were then contacted to fill the direct relationship matrix.

*Step 3*: Fuzzify and de-fuzzify the triangular fuzzy numbers (TFNs) to a crisp value.
*Step 4*: Normalisation of the direct relationship matrix (N).
*Step 5*: Creating the total-relation matrix.
*Step 6*: Producing the causal diagram

The results for steps 3,4,5 and 6 can be seen in section 4.

## 4. Results and Discussion

This section presents the results for the fuzzy DEMATEL. Based on scale provided in Table 2, the direct relationship matrix was prepared for each respondent. Table 3 presents the direct relationship matrix for respondent 1.

Table 3. Direct relationship matrix for respondent 1

| | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 | F11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **F1** | No | No | No | No | No | No | No | No | No | No | VH |
| **F2** | VH | No | VH | L | H | VH | L | VL | VL | L | VH |
| **F3** | VH | VL | No | VL | VL | VL | VL | VL | VL | VL | VH |
| **F4** | VH | H | L | No | VH | VL | No | L | H | VH | VH |
| **F5** | VH | L | L | L | No | L | L | VL | L | L | VH |
| **F6** | VH | L | VH | No | VH | No | L | L | L | L | VH |
| **F7** | VH | L | H | H | VH | H | No | VH | H | H | VH |
| **F8** | VH | L | H | H | H | H | L | No | H | L | VH |
| **F9** | VH | L | L | L | H | H | L | L | No | H | VH |
| **F10** | VH | VL | VL | H | H | H | L | H | H | No | H |
| **F11** | H | L | L | L | L | L | H | L | L | L | No |

After the direct relationship matrix was established, the next step was to fuzzify the matrix based on the scale provided in Table 3. This step was repeated for each respondent. After fuzzification, de-fuzzification was performed. Then, based on the de-fuzzified matrices of all respondents, the aggregate crisp scores were calculated. Post that, the normalization of the direct relationship matrix was done. The normalized matrix is presented in Table 4.

Table 4. Normalised matrix

| | **F1** | **F2** | **F3** | **F4** | **F5** | **F6** | **F7** | **F8** | **F9** | **F10** | **F11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **F1** | 0 | 0.007 | 0.0034 | 0.0212 | 0.017 | 0.0106 | 0.007 | 0.011 | 0.01 | 0.0034 | 0.1048 |
| **F2** | 0.1 | 0 | 0.1004 | 0.039 | 0.075 | 0.1091 | 0.043 | 0.028 | 0.024 | 0.0506 | 0.1004 |
| **F3** | 0.096 | 0.036 | 0 | 0.0277 | 0.024 | 0.0355 | 0.031 | 0.028 | 0.035 | 0.0239 | 0.1004 |
| **F4** | 0.105 | 0.083 | 0.0503 | 0 | 0.109 | 0.0277 | 0 | 0.047 | 0.079 | 0.1007 | 0.0961 |
| **F5** | 0.109 | 0.047 | 0.0465 | 0.0427 | 0 | 0.0503 | 0.05 | 0.031 | 0.054 | 0.0506 | 0.1004 |
| **F6** | 0.1 | 0.036 | 0.1091 | 0 | 0.109 | 0 | 0.047 | 0.05 | 0.059 | 0.0587 | 0.1048 |
| **F7** | 0.1 | 0.04 | 0.0747 | 0.0874 | 0.105 | 0.0834 | 0 | 0.1 | 0.092 | 0.0788 | 0.0961 |
| **F8** | 0.1 | 0.047 | 0.0918 | 0.079 | 0.079 | 0.0874 | 0.047 | 0 | 0.079 | 0.0356 | 0.1004 |
| **F9** | 0.105 | 0.051 | 0.0503 | 0.0503 | 0.079 | 0.079 | 0.039 | 0.043 | 0 | 0.0831 | 0.1004 |
| **F10** | 0.1 | 0.024 | 0.0205 | 0.0874 | 0.079 | 0.0788 | 0.043 | 0.083 | 0.079 | 0 | 0.0788 |
| **F11** | 0.083 | 0.051 | 0.039 | 0.0431 | 0.051 | 0.0503 | 0.083 | 0.043 | 0.036 | 0.0465 | 0 |

The next step was the creation of the total relationship matrix which has been presented in Table 5.

Table 5. Total relationship matrix

| | **F1** | **F2** | **F3** | **F4** | **F5** | **F6** | **F7** | **F8** | **F9** | **F10** | **F11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **F1** | 0.041 | 0.026 | 0.0265 | 0.0405 | 0.046 | 0.0348 | 0.028 | 0.03 | 0.032 | 0.0263 | 0.1375 |
| **F2** | 0.228 | 0.057 | 0.1708 | 0.0984 | 0.163 | 0.1791 | 0.101 | 0.089 | 0.095 | 0.1166 | 0.2292 |
| **F3** | 0.177 | 0.072 | 0.0483 | 0.0683 | 0.084 | 0.0855 | 0.07 | 0.067 | 0.079 | 0.0683 | 0.1817 |
| **F4** | 0.239 | 0.139 | 0.1245 | 0.0685 | 0.198 | 0.1128 | 0.064 | 0.108 | 0.147 | 0.1669 | 0.2309 |
| **F5** | 0.22 | 0.095 | 0.11 | 0.0977 | 0.083 | 0.1179 | 0.1 | 0.086 | 0.114 | 0.11 | 0.2124 |
| **F6** | 0.229 | 0.091 | 0.1758 | 0.0664 | 0.191 | 0.0797 | 0.105 | 0.109 | 0.126 | 0.1228 | 0.2329 |
| **F7** | 0.273 | 0.117 | 0.1715 | 0.1684 | 0.224 | 0.1842 | 0.077 | 0.177 | 0.184 | 0.1689 | 0.2686 |
| **F8** | 0.247 | 0.111 | 0.1724 | 0.1447 | 0.181 | 0.1704 | 0.11 | 0.069 | 0.155 | 0.1154 | 0.2469 |
| **F9** | 0.237 | 0.108 | 0.1257 | 0.1143 | 0.172 | 0.1565 | 0.099 | 0.106 | 0.075 | 0.1503 | 0.2328 |
| **F10** | 0.236 | 0.087 | 0.1013 | 0.15 | 0.176 | 0.1573 | 0.102 | 0.144 | 0.152 | 0.0767 | 0.2164 |
| **F11** | 0.191 | 0.096 | 0.1023 | 0.0966 | 0.129 | 0.1159 | 0.126 | 0.095 | 0.096 | 0.1041 | 0.1138 |

In the end, the sum of rows (R) and columns (C) was calculated. Based on R+C and R-C values (Table 6), the factors were divided into cause-and-effect groups as shown in Figure 2. Factors in quadrants 1 and 2 are cause factors and ones in quadrants 3 and 4 are effect factors.

Table 6. Sum of rows and columns for grouping the factors

| | R | C | R+C | R-C | Grouping |
|---|---|---|---|---|---|
| **F1** | 0.468998 | 2.317402 | 2.7864 | -1.848404 | Effect |
| **F2** | 1.527426 | 0.998887 | 2.526313 | 0.528539 | Cause |
| **F3** | 1.000143 | 1.329279 | 2.329422 | -0.329136 | Effect |
| **F4** | 1.599172 | 1.11378 | 2.712953 | 0.485392 | Cause |
| **F5** | 1.345154 | 1.646817 | 2.991972 | -0.301663 | Effect |
| **F6** | 1.529478 | 1.394132 | 2.923611 | 0.135346 | Cause |
| **F7** | 2.013032 | 0.98083 | 2.993862 | 1.032201 | Cause |
| **F8** | 1.722818 | 1.08089 | 2.803709 | 0.641928 | Cause |
| **F9** | 1.575638 | 1.253811 | 2.829448 | 0.321827 | Cause |
| **F10** | 1.597564 | 1.226285 | 2.823849 | 0.371279 | Cause |
| **F11** | 1.265779 | 2.303087 | 3.568867 | -1.037308 | Effect |

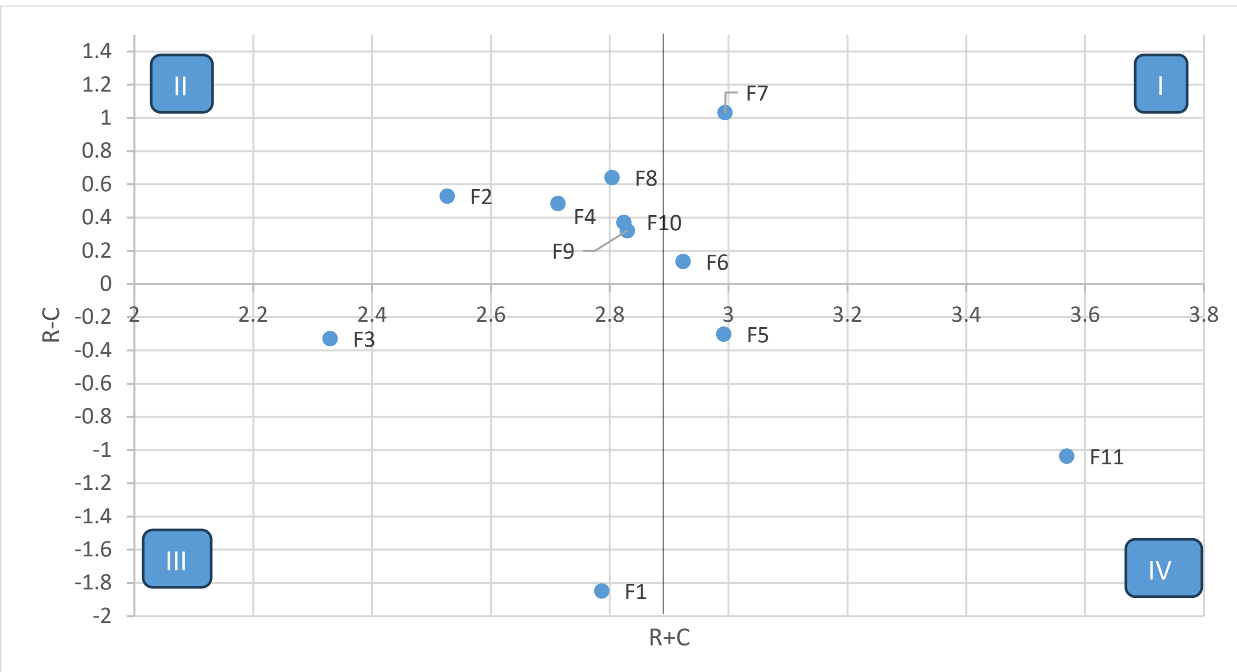


Figure 2. Cause-and-effect diagram

The results reveal that Lack of requisite skills (F7) and Privacy protection (F6) are the most important factors as they are the cause factors and have high prominence (1st quadrant). These factors are highly interconnected in the system and hence, they easily influence other factors. Scalability (F5) and Lack of top-management support (F11) are the next two important factors (4th quadrant). These are effect factors that are highly connected in the network. And hence, get easily influenced by other factors. The factors in the second quadrant Network throughput (F9), Implementation costs (F10), Legal and regulatory compliance (F2), energy consumption (F4), and System integration (F8) are the next important factors (2nd quadrant). These are also the cause factors which impact the effect factors in the 3rd and 4th quadrants.

## 5. Conclusion

This study aimed to identify the factors that pose a barrier to the integration of Blockchain technology with Additive manufacturing. First, the factors were identified from the literature. Then, using fuzzy DEMATEL, the hierarchical and cause-and-effect relationship between the factors was established. This study fills an existing gap in the literature by integrating 2 Industry 4.0 technologies. First. AM is used as a means to tackle resilience, mass customization, and environmental sustainability needs. Then, Blockchain is used to mitigate the risks associated with AM. However, this study goes a step ahead in identifying the barriers to the integration of these technologies. Practitioners can use the results to understand how to improve the performance of AM and be aware of the risks associated with blockchain integration with AM. The study also has some limitations. The study also has some limitations. Despite being highly useful for firms and researchers, the study cannot be generalised because due to a smaller number of respondents and just a few representative sectors. The results could further be validated through an empirical study or case studies from various sectors. Based on the results, the study groups the factors in cause and effect. These factors can then be used to propose a model which can be quantitatively tested using structural equation Modelling and qualitatively verified using semi-structured interviews.

## References


Alkaabi, N., Salah, K., Jayaraman, R., Arshad, J., & Omar, M,. Blockchain-based traceability and management for additive manufacturing. *IEEE access*, *8*, 188363-188377, 2020.

ASTM F2792-12. Standard Terminology for Additive Manufacturing Technologies. In *ASTM International: Vol. West Consh*, 2021

Berman, B., Managing the Disruptive Effects of 3D Printing. *Rutgers Business Review*, *5*(3), 294-309, 2020.

Calle, G., DiCaprio, A., Stassen, M., & Manzer, A., Can blockchain futureproof supply chains? A Brexit case study. In *Disruptive innovation in business and finance in the digital world* (pp. 101-122). Emerald Publishing Limited, 2019.

Chan, H. K., Guo, M., Zeng, F., Chen, Y., Xiao, T., & Griffin, J., Blockchain-enabled authentication platform for the protection of 3D printing intellectual property: a conceptual framework study. *Enterprise Information Systems*, 2180776, 2023.

Efthymiou, M., McCarthy, K., Markou, C., & O'Connell, J. F., An exploratory research on blockchain in aviation: the case of maintenance, repair and overhaul (MRO) organizations. *Sustainability*, *14*(5), 2643, 2022.

Engelmann, F., Holland, M., Nigischer, C., & Stjepandić, J., Intellectual property protection and licensing of 3d print with blockchain technology. *Transdisciplinary Engineering Methods for Social Innovation of Industry*, *4*(2), 103-112, 2018.

Esmaeilian, B., Deka, A., & Behdad, S., A blockchain platform for protecting intellectual property: Implications for additive manufacturing. In *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference* (Vol. 59223, p. V004T05A011). American Society of Mechanical Engineers, 2019.

Guo, D., Ling, S., Li, H., Ao, D., Zhang, T., Rong, Y., & Huang, G. Q., A framework for personalized production based on digital twin, blockchain and additive manufacturing in the context of Industry 4.0. In *2020 IEEE 16th International Conference on Automation Science and Engineering (CASE)* (pp. 1181-1186). IEEE, 2020.

Holland, M., Stjepandić, J., & Nigischer, C., Intellectual property protection of 3D print supply chain with blockchain technology. In *2018 IEEE International conference on engineering, technology and innovation (ICE/ITMC)* (pp. 1-8). IEEE, 2018.

Kar, S., Kasimsetty, V., Barlow, S., & Rao, S., *Risk analysis of blockchain application for aerospace records management* (No. 2019-01-1344). SAE Technical Paper, 2019.

Kumar, R., Choudhary, D., Bang, P., Dua, A., & Sangwan, K. S., A Blockchain Technology based Framework for Environmental and Social Impact Authenticity of a 3D Printed Product. *Procedia CIRP*, *116*, 281-286, 2023.

Li, M., Fu, Y., Chen, Q., & Qu, T., Blockchain-enabled digital twin collaboration platform for heterogeneous socialized manufacturing resource management. *International Journal of Production Research*, *61*(12), 3963-3983, 2023.

Priyadarshini, J., Singh, R. K., Mishra, R., Chaudhuri, A., & Kamble, S., Supply chain resilience and improving sustainability through additive manufacturing implementation: a systematic literature review and framework. *Production Planning & Control*, 1-24, 2023.

Ragot, S., Rey, A., & Shafai, R., IP lifecycle management using blockchain and machine learning: Application to 3D printing datafiles. *World Patent Information*, *62*, 101966, 2020.

Rinaldi, M., Caterino, M., Fera, M., Manco, P., & Macchiaroli, R., Technology selection in green supply chains - the effects of additive and traditional manufacturing. *Journal of Cleaner Production*, *282, 124554*, 2021. https://doi.org/10.1016/j.jclepro.2020.124554

Singh, A. K., & Kumar, V. R., Smart Contracts and Supply Chain Management Using Blockchain. *Journal of Engineering Research (2307-1877)*, 2022.

Vatankhah Barenji, A., Li, Z., Wang, W. M., Huang, G. Q., & Guerra-Zubiaga, D. A., Blockchain-based ubiquitous manufacturing: A secure and reliable cyber-physical system. *International Journal of Production Research*, *58*(7), 2200-2221, 2020.

Walthall, R., *Unsettled Topics Concerning Adopting Blockchain Technology in Aerospace* (No. EPR2020021). SAE Technical Paper, 2020.

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