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Advancing Sustainable Construction: A Systematic Review of the Role of Blockchain Technology in 3D Concrete Printing

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Article

Advancing Sustainable Construction: A Systematic Review of the Role of Blockchain Technology in 3D Concrete Printing

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Abstract: This systematic review explores how blockchain technology (BcT) can enhance the sustainability, efficiency, and transparency of 3D concrete printing (3DCP) in the construction industry. BcT offers promising solutions to persistent challenges such as resource inefficiencies, lack of transparency, and complex project management. 3DCP, as a cutting-edge construction method, has shown potential in reducing waste, optimizing resources, and enabling intricate designs that traditional methods struggle to achieve. However, its adoption is slowed by supply chain and execution issues. Blockchain's decentralized and immutable nature allows for secure, traceable, and transparent data management, improving material tracking and automating workflows via smart contracts. Following PRISMA guidelines, an initial search identified 767 papers from Web of Science and Scopus, and through an extended search using additional keywords, a total of 3,227 materials were found. After applying inclusion/exclusion criteria, 10 studies were analyzed through scientometric and content analysis. The review highlights blockchain's potential to promote material reuse and support circular economy principles, improving 3DCP's sustainability. While promising, the integration of these technologies lacks real-world case studies, underscoring the need for further research. This review positions blockchain as a key driver for advancing sustainable practices in 3DCP.

Keywords: blockchain technology; 3D concrete printing; sustainable development goals; smart contracts; construction efficiency; project transparency

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1. Introduction

The construction industry is at a critical juncture, faced with the dual challenges of meeting growing urbanization demands while minimizing its significant environmental footprint [1]. Traditionally, construction has been one of the most resource-intensive industries, contributing to carbon emissions [1–3], waste generation [4,5], and excessive energy use [2,6,7]. In response to these challenges, sustainable construction practices have gained prominence [3,5], focusing on creating built environments that meet present needs without compromising the ability of future generations to meet theirs. These practices emphasize resource efficiency, waste minimization, renewable energy use, and the adoption of environmentally friendly materials and techniques throughout the lifecycle of a building, from design and construction to operation and eventual decommissioning.

One of the key principles of sustainable construction is reducing resource consumption [1,8], which is where emerging technologies like 3D concrete printing (3DCP) come into play. 3DCP, an advanced form of additive manufacturing that allows for the creation of complex concrete structures with a high degree of precision and customization, enables the construction of complex, custom-designed structures with a level of precision and material efficiency that is difficult to achieve using traditional construction methods [5]. By automating certain processes, 3DCP reduces the need for formwork, minimizes human error, and can significantly cut down on construction waste. Additionally, the ability to print complex geometries enables more innovative use of space and

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materials, reducing overall energy use and improving the sustainability profile of the construction project.

Despite its promise, the broader adoption of 3DCP still faces challenges, particularly in ensuring the sustainability of supply chains [9,10], enhancing process transparency [11], and managing project workflows more efficiently [12]. This is where blockchain technology (BcT) can offer transformative potential [13–16]. Blockchain, initially developed as the underlying technology for cryptocurrencies like Bitcoin, has since found applications across various industries due to its ability to create secure, transparent, and immutable records of transactions and data exchanges [17,18]. These features make blockchain particularly suitable for addressing some of the inefficiencies and opacity that plague the construction industry.

In the context of construction, blockchain technology can be applied to several critical areas. Firstly, it can enable supply chain transparency by tracking the origin, movement, and certification of construction materials in real-time [16,19–22]. This ensures that materials used in projects comply with sustainability standards, reducing the risk of fraud or the use of substandard materials. Secondly, blockchain can improve project management by providing an unalterable record of every transaction, contract, and milestone in the construction process [23–26]. This level of transparency fosters greater trust among stakeholders, reduces disputes, and ensures accountability throughout the project lifecycle.

Furthermore, smart contracts, a key feature of blockchain, have the potential to automate various administrative tasks, such as payments, subcontractor agreements, and procurement processes [16,20]. Once predefined conditions are met, such as the completion of a certain construction phase, payments can be automatically released to contractors, reducing delays and administrative overhead [27,28]. This automated process improves efficiency and ensures that projects stay on track, while also reducing the potential for corruption or mismanagement.

Blockchain's ability to offer data security is another advantage [29], particularly in the construction of large infrastructure projects where multiple stakeholders, including governments, contractors, suppliers, and financiers, are involved. The decentralized nature of blockchain ensures that data remains secure and cannot be tampered with [30], providing a reliable system of record for all parties involved.

Recent research has begun exploring how blockchain can enhance the sustainability of construction projects by enabling more circular economy practices [31,32]. By tracking the lifecycle of materials from production to disposal, blockchain can support material recycling efforts, allowing construction firms to minimize waste and reuse resources [32]. This is particularly relevant in 3DCP, where precise material use is key to maximizing sustainability.

This review seeks to systematically examine the existing literature to understand how blockchain technology can enhance the sustainability, efficiency, and transparency of 3D concrete printing. By exploring this intersection of technologies, the study aims to highlight not only the current state of research but also the gaps and opportunities for future studies. Specifically, this paper addressed how blockchain can support sustainable construction practices, streamline project management, and improve stakeholder confidence by providing more secure, transparent, and accountable construction processes.

In doing so, this review contributes to a growing body of knowledge that positions blockchain technology as a key enabler of next-generation construction practices, particularly in its application to 3D concrete printing. The potential to transform construction workflows, coupled with the environmental benefits of 3DCP, aligns with broader global initiatives toward creating more resilient, eco-friendly, and cost-effective built environment. As the construction industry moves toward more digitally integrated construction practices, understanding the synergies between blockchain and 3DCP will be critical for advancing sustainable development goals in the built environment.

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2. Materials and Methods

2.1. Search Strategy

The authors performed a systematic review following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [33] to ensure a comprehensive and methodologically sound approach. The initial search was performed in June 2024, using two major databases, Web of Science and Scopus, known for their broad coverage of high-quality peer-reviewed literature. These databases were selected based on their extensive indexing of scientific journals, books, conferences, and workshops, providing access to the most relevant literature on blockchain technology (BcT) and 3D concrete printing (3DCP) in construction.

The search terms were carefully chosen to capture the intersection of BcT and 3DCP in the context of sustainability, efficiency, and transparency in the construction industry. Initial keywords used included "3D concrete printing," "3DCP," "blockchain technology," "smart contracts," "industry 4.0," and "sustainable construction." A comprehensive search string was developed through a scientometric analysis using *VOSviewer* to identify additional keywords and emerging trends. The nearest-neighbour principle [34] was equally employed to expand the keyword pool and ensure no relevant studies were missed. An extended search identified 3,227 materials, ensuring an exhaustive coverage of the relevant literature.

Additional steps were taken to refine the search protocol, ensuring that grey literature and non-reproducible sources such as Google Scholar were excluded to maintain the high scientific rigor of the review. Full-text articles were retrieved without year restrictions, allowing for a thorough examination of the historical and current development of blockchain applications in construction. Furthermore, multiple iterations of the search string were tested and refined to ensure comprehensiveness, focusing on peer-reviewed, high-quality materials from reputable sources. The scientometric analysis was performed using *VOSviewer* and the steps are outlined in Figure 1.

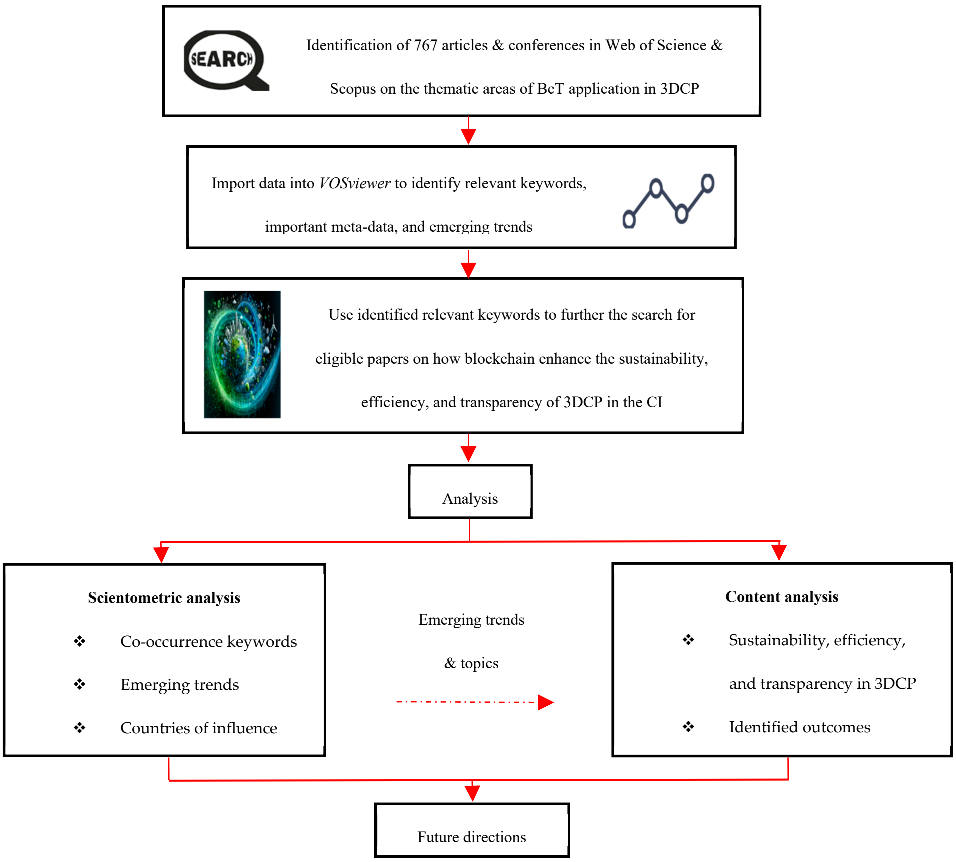

Figure 1. Systematic review process of how BcT enhance the sustainability, efficiency, and transparency of 3DCP practice.

The authors developed a search protocol through the initial search. The search protocol was applied on the scientific databases of Web of Science and Scopus to gather all the papers relevant for the research topic. The primary keywords were explored using the nearest neighbour criteria [34] to determine how other scholars captured the different terms in order to be comprehensive with the search criteria for the systematic review. A cursory look at studies on the different primary keywords culminated in the search terms for this systematic review.

Figure 2 presents a visualization of most of the co-occurring keywords used to develop the expanded search string.

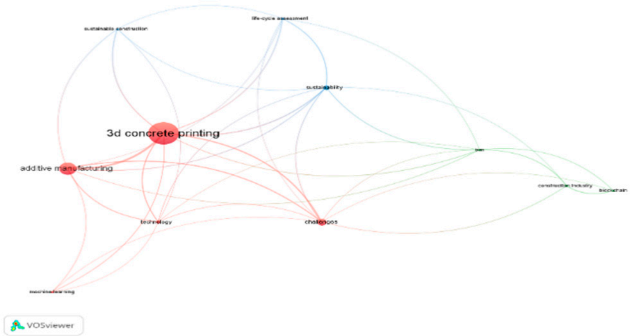

Figure 2. Visualization of keywords co-occurrences from initial article search.

According to [35] 3D Concrete printing include terms such as 3DCP, additive manufacturing, modular construction, 3D printed concrete, and off-site construction. Blockchain technology included Blockchain, Bitcoin, industry 4.0, smart contracts, machine learning, and cryptography [36]. However, in the search using Bitcoin as a search term, the search identified a huge number of papers that were related to economics topics in cryptocurrencies, rather than technological aspects of Blockchain technology related to 3DCP. Therefore, since the study was about mapping how blockchain technology affects sustainability, efficiency, and traceability of 3DCP, the study process was to find and review the papers related to technical aspects of Blockchain technology hence, the term Bitcoin was dropped. It is expected that by using only the other terms besides Bitcoin, in the search string, the majority of Bitcoin-related papers with a technical perspective on Blockchain were still included. In addition, it seemed that if a Bitcoin-related paper did not have the term Blockchain anywhere in its meta-data, the paper was related to the economics of a cryptocurrency. Sustainable construction according to [37] was mostly presented as green concrete, green, green building, sustainable development, clean energy, cleaner production, climate change, eco, eco-efficient, eco efficient, economic, energy, environment, global warming, green seal, greenhouse gases, impact environmental, natural resources, recycle, renewable energy, renewable resources, reuse, reverse logistic, social, socioeconomic, socio-environmental, sustain, sustainable business model, water reuse, sustainable certification, and environmental certification.

These search terms were operationalized to comprehensively elicit articles for the systematic review on the role of blockchain technology in advancing the sustainability of 3DCP. After designing and testing the search protocol, the authors chose the scientific databases for the searches. The study initially sought for peer-reviewed, high-quality papers published in conferences, workshops, symposiums, books and journals related to the research topic. Two databases were used for paper retrieval. The chosen databases were Scopus and Web of Science. The authors decided not to use grey literature and non-reproducible databases like Google scholar searches and retained scientific peer review as an important criterion.

To ensure sufficient coverage, Scopus, and Web of Science were chosen. Web of Science covers all journals indexed in Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI), Arts and Humanities Citation Index (AHCI), and Emerging Sources Citation Index (ESCI), while Scopus has a large database indexing over 24,600 active titles and over 5000 publishers. Full-text articles were investigated without any year/period restrictions to provide a full account of the literature, progress and development of the study area. The search string was operationalised thus.

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(TITLE-ABS-KEY(3D concrete printing) OR TITLE-ABS-KEY(3DCP) OR TITLE-ABS-KEY(modular construction) OR TITLE-ABS-KEY(3D printed concrete) OR TITLE-ABS-KEY(off-site construction) AND TITLE-ABS-KEY(Blockchain technology) OR TITLE-ABS-KEY(blockchain) OR TITLE-ABS-KEY(industry 4.0) OR TITLE-ABS-KEY(smart contract) OR TITLE-ABS-KEY(machine learning) OR TITLE-ABS-KEY(cryptography) AND TITLE-ABS-KEY(Sustainable construction) OR TITLE-ABS-KEY(green concrete) OR TITLE-ABS-KEY(green) OR TITLE-ABS-KEY(green building) OR TITLE-ABS-KEY(sustainable development) OR TITLE-ABS-KEY(clean energy) OR TITLE-ABS-KEY(cleaner production) OR TITLE-ABS-KEY(climate change) OR TITLE-ABS-KEY(eco) OR TITLE-ABS-KEY(eco-efficient) OR TITLE-ABS-KEY(energy) OR TITLE-ABS-KEY(economy) OR TITLE-ABS-KEY(environment) OR TITLE-ABS-KEY(global warming) OR TITLE-ABS-KEY(green seal) OR TITLE-ABS-KEY(greenhouse gases) OR TITLE-ABS-KEY(impact environmental) OR TITLE-ABS-KEY(natural resources) OR TITLE-ABS-KEY(recycle) OR TITLE-ABS-KEY(renewable energy) OR TITLE-ABS-KEY(renewable resources) OR TITLE-ABS-KEY(reuse) OR TITLE-ABS-KEY(reverse logistic) OR TITLE-ABS-KEY(social) OR TITLE-ABS-KEY(socioeconomic) OR TITLE-ABS-KEY(socio-environmental) OR TITLE-ABS-KEY(sustain) OR TITLE-ABS-KEY(sustainable business model) OR TITLE-ABS-KEY(water reuse) OR TITLE-ABS-KEY(sustainable certification) OR TITLE-ABS-KEY(environmental certification)) AND (LIMIT-TO (LANGUAGE, “English")).

2.2. Inclusion and Exclusion Criteria

A rigorous set of inclusion and exclusion criteria was applied to ensure that only the most relevant studies were considered. The search initially yielded 3,227 materials, of which 702 were identified as duplicates and removed. After title and abstract screening, 473 articles were excluded because they did not align with the core themes of blockchain and 3DCP in construction. Studies that were not published in English or were not peer-reviewed were also excluded, with 13 non-English papers removed.

The remaining 2,039 papers underwent further scrutiny based on the relevance of their abstracts and methodologies. Articles that did not specifically address blockchain technology’s application to 3DCP, or those that discussed BcT in unrelated sectors (e.g., cryptocurrencies or general automation) without a construction focus, were excluded. A total of 1,700 papers were removed after full-text review, as they did not meet the strict criteria for inclusion in this review. Additionally, studies that lacked sufficient methodological rigor, such as those based on unverified data or those that presented only speculative insights, were also excluded.

Ultimately, 10 high-quality, peer-reviewed articles were selected for in-depth content analysis. These studies provided empirical evidence and detailed insights into how blockchain technology can enhance sustainability, efficiency, and transparency in 3DCP processes. The application of inclusion/exclusion criteria was particularly crucial in ensuring that only studies with a strong methodological foundation and clear relevance to the research question were included in the final review.

Figure 3 presents the preferred reporting items for systematic review and meta-analysis flow chart, as applied in the study.

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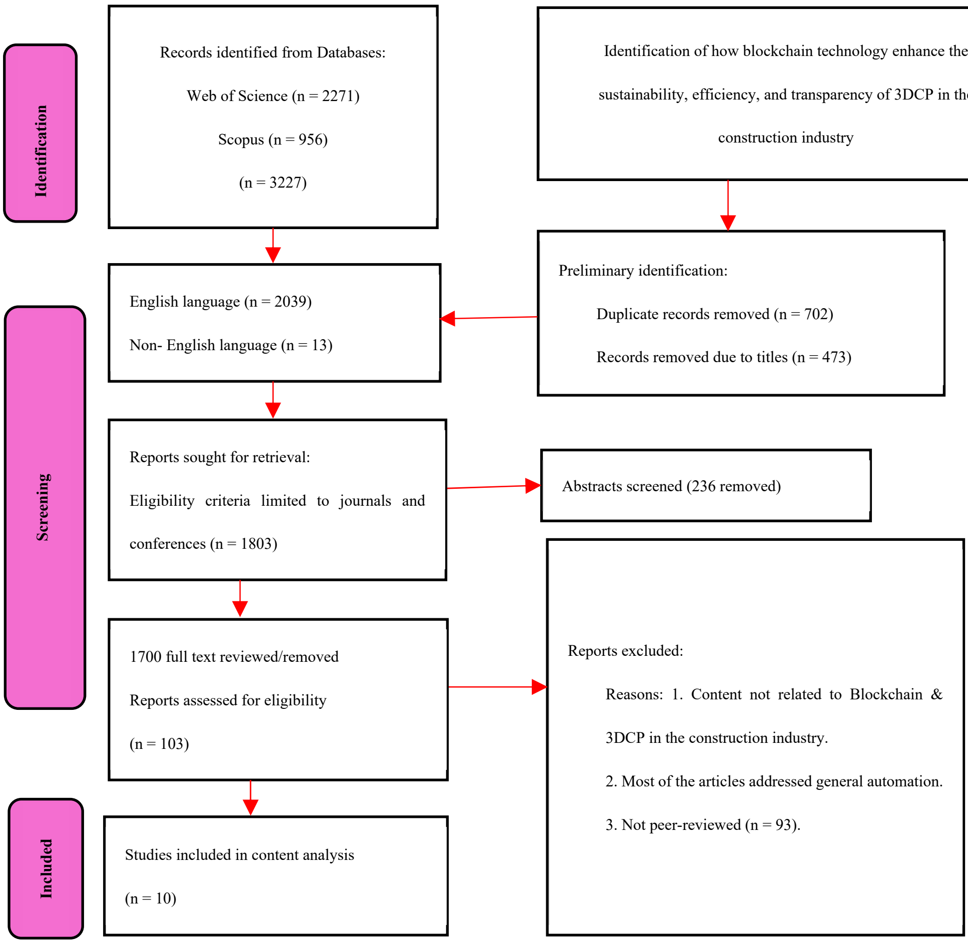

Figure 3. Preferred Reporting Items for Systematic Reviews (PRISMA) for the study.

2.3. Data Extraction and Analysis

The study extracted data from the articles about the Authors, year of publication, country of publication, strategies employed, interventions addressed, and main findings concerning the contribution to sustainability. A thematic content analysis was then performed. The data was equally ranked in terms of low-medium-high income countries to assess any prevailing patterns.

2.4. Quality Assessment

The critical appraisal and quality assessment of primary research are key stages in systematic reviews [38]. Reviews are only as good as the studies upon which they are based. Although quality assessment of primary qualitative research remains a contested area, it is important to device effort to ensure some form of quality criteria for any qualitative research. In addition to ensuring that only peer-reviewed articles were included in the study, the Critical Appraisal Skills Programme (CASP) [39,40] was equally employed in assessing the trustworthiness, relevance and results of the systematic review. The following questions were used to ensure quality: (1) Was the search for relevant primary studies to include in the review detailed and exhaustive? (2) Was the protocol used to select studies for inclusion in the review appropriate? (3) Were the included primary studies of high methodological quality? and (4) Were the assessments of the studies reproducible?

3. Scientometric Analysis

The scientometric analysis was performed using *VOSViewer* [41–43]. The analysis enabled the visualisation of the influence of key journals, publications, and countries, as well as analyse the co-occurrence keywords. The co-occurrence keywords analysis is a mapping of commonly adopted key

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contents in the body of literature [17–20]. This section presents analysis of co-occurrence keywords, and the countries actively contributing to the research domain. The scientometric analysis equally feeds into the development of the content analysis.

3.1. Co-Occurrence Keywords

The mapping of co-occurrence keywords indicated the frequency of occurrence of author keywords of identified studies and the inter-relationship among the different studies [44]. By visualizing the relationships between the keywords, each keyword can be grouped into categories and clusters that provide information about the main study area of this review. Certain criteria guided the inclusion and exclusion of selected keywords: (1) The threshold value of a minimum of two co-occurrences; (2) the exclusion of general keywords such as construction, buildings, designs, literature review or systematic review; (3) the merger of similar words conveying the same meaning for example blockchain, block-chain, industry 4.0, and cryptography were merged. Sustainable construction and sustainability were equally merged. 3D printing included modular construction, modularity, additive manufacturing, off-site construction, and prefabrication. Finally, a total of 6 main keywords were shortlisted and visualized in Figure 4.

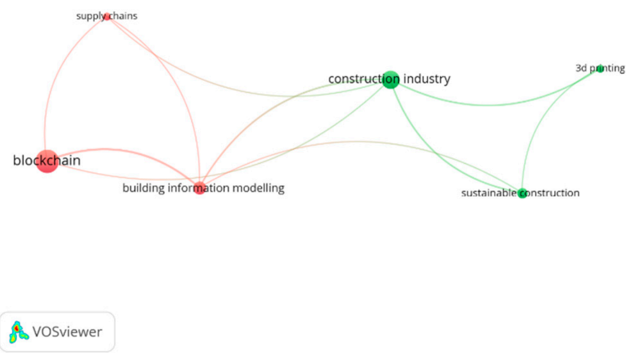

Figure 4. Visualization of keywords co-occurrences from final article search.

From Figure 4, it is evident that the link between blockchain and 3D printing in the construction industry is still distant and can be likened to the dearth of literature in this area of study. The items with the same colour represent the same cluster. There are two distinct clusters embedding the thematic areas of this study. The analysis of the interrelationship visualized in Figure 4 corroborated evidence from extant literature and interpreted in the following manner.

a. Blockchain has mostly been applied in a general term with Building Information Modelling to enable a seamless supply chain operation in the construction industry [6,7,22–24].

b. 3D concrete printing is one of the innovations that is driving sustainable construction [7,46].

The scientometric analysis provided six pointers from the ten papers. The points are linked to the use of blockchain technology to enhance the sustainability, efficiency, and transparency of 3D concrete printing in the construction industry. An in-depth content analysis is performed and presented in section 4 of the paper.

3.2. Analysis of Countries Contributing to the Research Domain

The R-studio was used to explore the prominent countries within the literature. From the selected articles, the Republic of China is leading in the application of Blockchain technology in 3DCP. The United States of America, the United Kingdom, Germany, Singapore and Italy are equally front-line countries in the application of Blockchain technology in 3DCP as shown in Figure 5.

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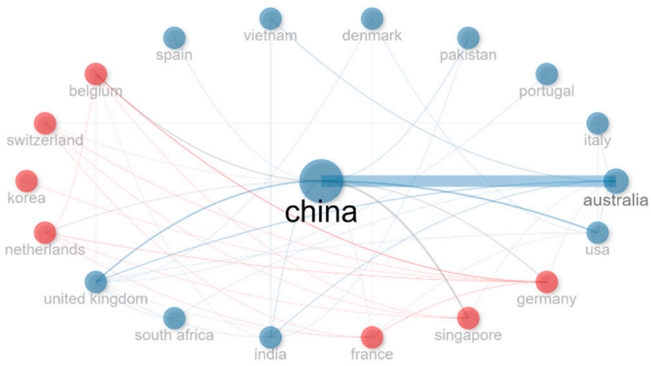

Figure 5. Countries of influence on implementing Blockchain technology in 3DCP.

There is a noticeable growth in the thematic area of 3DCP. Over the years, different authors have approached the research from an evolving prism including digital construction [12], reinforcement [7], additive manufacturing [46], rheology, printability [47], and buildability [3] as shown in Figure 6, forming major talking points within the domain of 3DCP.

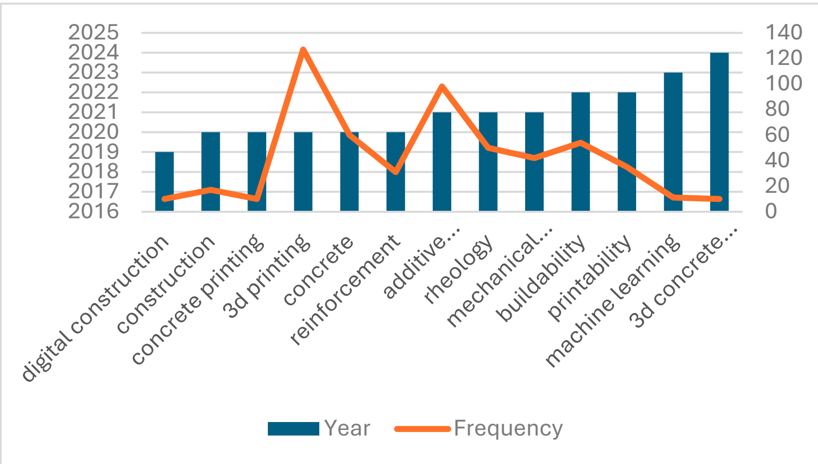

Figure 6. Emerging trends in 3D concrete printing literature.

Table 1. Included studies related to application of blockchain technology in 3D concrete printing

The selected articles are	Communication / Lean construction	G.P Gallo, R Romano, E Belardi	2021	Italy	High	Case study	Sustainability of prefabrication	Quality controls over the final product. Certainty of times and costs control of the building process	[46]
Sustainability	Lean automation	F. Feldmann	2022	Germany	High	Literature	Automation in modular prefabrication	Energy and waste reduction, Shorter construction times, Increased	[7]

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Theme	Efficiency Transparency	Efficiency	Efficiency	Efficiency Transparency	Efficiency Transparen	Efficiency Transparency	Transparency	Transparency
Focus	Communication	Communication	Communication	Communication	Communication	Communication	Communication	Smart contract
Author(s)	R. Brandín, S. Abrishami,	Q Chen, B Heydari,	Y Liu, X Tao, M Das, X Gong, H	BPY Loo, RWM Wong	L Wu, X Li, R Zhao, W Lu, J Xu,	L Wu, W Lu, F Xue, X Li, R	L Wu, W Lu, R Zhao, J Xu, X Li, F	G. Chen, M. Liu, H. Li, S. M. Hsiang, A. Jarvamard,
Year	2021	2021	2024	2023	2022	2022	2022	2023
Country	United	United	China	China	China	Hong Kong	Hong Kong	Singapore
Economy	High	High	Upper	Upper Medium	Upper	High	High	High
Strategy	Exploratory	Experim	OpenBIM	Case study	Design	Design	Design	Simulation
Intervention	Off-site manufacturing	Knowledge	Interoperability and	Smart modular integrated	Cross-border	Off-site production	Information sharing	Quantifying subcontractors'
Contribution to sustainability	Information traceability of physical and digital assets, Data automation and information	An average 75% reduction in the number of	Workflow standardization. Data completeness and integrity	Just-in-time transportation and on-site installation. Monitoring, authentication, and certifications for information	Product accountability. Data traceability. Security through	Avoid a single point of failure in IoT networks. Ensure the provenance	Allow project participants to endorse information about the modules and	Smart contracts exhibited incentives to motivate reliable contributions and enable peer negotiations to realize task-level production
Ref	[10]	[45]	[14]	[12]	[11]	[29]	[48]	[13]

4. Content Analysis

The scientometric analysis enabled a cursory view of the thematic areas within the study. However, it did not demonstrate how Blockchain was applied in the different studies and the implication for the different thematic areas of sustainability, efficiency, and traceability. Following the bibliometric and scientometric analysis, a content analysis was conducted to summarize how Blockchain technology impacted the sustainability, efficiency, and traceability of 3D concrete printing practices in the construction industry. The content analysis was conducted to explore the implication of Blockchain technology in 3DCP towards sustainability, efficiency, and traceability.

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4.1. Overview of Included Papers

A total of ten papers were analyzed. Majority of the papers were from the Republic of China and Hong Kong. Others were from the United States of America, the United Kingdom, Singapore, Germany, and Italy. Most of these countries ranked as highly industrialized and high-income countries, except China which is still considered an upper-medium income country. The prevalent study design approach was design science research approach. Other research methods employed were experiment, case study, simulation, exploratory, openBIM, and literature review. Summary of the key findings are presented in the next section.

4.2. Summary of Key Findings

The key findings from the selected articles are presented in the different themes in a tabular form and discussed thereafter.

4.2.1. Sustainability

Two out of the ten papers related to the sustainability of 3DCP using Blockchain technology. The papers pertaining to sustainability as a contributory effect of Blockchain technology on 3D concrete printing practices are presented in Table 2.

Table 2. Summary of the review on sustainability effects of Blockchain technology in 3DCP.

Review focus	Main findings	Reference
Automation in modular construction	Energy and waste reduction. Shorter construction times.	[7]
Sustainability of prefabrication	Optimization of material use. Quality control of the final product. Minimize waste of time and materials during product design. Open system design for customization and integration of structural, energy, and cost specifications.	[46]

The papers presented different aspects of Blockchain technology application to 3DCP to enable sustainability. For example, the author [18] through a study rooted in literature review and expert interview, and focusing in automation in modular construction, opined that it is possible to reduce energy and construction waste with Blockchain technology. The author also posits that the application of Blockchain technology will reduce the time required to deliver a 3D construction project. In agreement, [46] extends the list in a case study while adding that application of Blockchain technology will enable the optimization of material use, ensure quality control of final 3D constructed product, as well as enable customization and integration of structural, energy, and cost specifications of 3D concrete printed structures.

4.2.2. Efficiency

The papers pertaining to the effect of Blockchain technology to enable efficiency of 3D concrete printing practices are presented in Table 3.

Table 3. Summary of the review of Blockchain technology on the efficiency of 3DCP.

Review focus	Main findings	Reference
Off-site manufacturing	Data automation and information management, enhancing efficiency in the supply chain ecosystem.	[10]

Knowledge transfer in interrelated tasks	A 50%-80% improvement in task completion efficiency, with a 75% reduction in iterations for success.	[45]
Automation in modular construction	Shorter construction times and increased quality.	[7]
Smart modular integrated construction	Just-in-time transportation and real-time project monitoring, ensuring more efficient operations.	[12]
Cross-border logistics in modular construction	Improved data traceability and accountability, ensuring efficiency through secure data management.	[11]

Contents of five papers were analyzed. The different authors approached the contribution of Blockchain technology to enable efficiency of 3DCP practices from diverse perspectives. For example, [10] in an exploratory study suggested the possibility of data automation and information management to enhance efficiency in the supply chain ecosystem of 3DCP. There is a 50% to 80% improvement in task completion efficiency, with a 75% reduction in iterations for a successful implementation of 3DCP with Blockchain technology according to [45]. Authors [16,18] approached efficiency from the perspective of shorter construction time and increased quality, as well as just-in-time transportation and real-time project monitoring, ensuring more efficient operations. Author [11] while focusing on cross-border logistics in modular construction, opined that Blockchain technology will improve data traceability and accountability, ensuring efficiency through data management.

4.2.3. Transparency

Four of the selected papers, presented the arguments in terms of the potential of Blockchain technology to enable transparency in 3DCP practices. One of the strengths of Blockchain technology is the provenance that it provides to supply chain [9,25]. The papers pertaining to the effect of Blockchain technology to enable transparency of 3D concrete printing practices are presented in Table 4.

Table 4. Summary of the review on transparency effects of Blockchain technology in 3DCP.

Review focus	Main findings	Reference
Off-site manufacturing	Information traceability of physical and digital assets. Data management brings transparency to stakeholders.	[10]
1. Quantifying subcontractors' marginal contributions 2. Distributing fair collaborative outcomes when project participants can perform at different levels of effort.	Smart contracts incentivize reliable contributions and enable peer negotiation, fostering transparency in collaborative tasks.	[13]
Smart modular integrated construction	Monitoring, authentication, and certifications for transparent information sharing and real-time updates.	[12]
Cross-border logistics in modular construction	Data traceability and security via immutability and non-repudiation, ensuring transparency in logistics.	[11]

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According to [10] Blockchain technology enables information traceability of physical and digital assets. The authors further add that data management brings transparency to stakeholders and enables confidence. In a study conducted by [13] and focusing on quantifying subcontractors' marginal contributions, and distributing fair collaborative outcomes when project participants can perform at different levels of effort, it was opined that Blockchain-enabled smart contracts will incentivize reliable contributions and enable peer negotiation, fostering transparency in collaborative tasks. Blockchain technology enables the monitoring, authentication, and certification for transparent information sharing and real-time updates [12]. The authors [11] argue that 3DCP data traceability and security via immutability and non-repudiation, will ensure transparency in 3DCP logistics.

Based on the deductions from the scientometric as well as content analysis, the immediate future directions for Blockchain technology application in 3DCP practices are stakeholder management, logistics and faster approval processes, as well as smart contracts.

5. Conclusions

The combination of blockchain technology (BcT) and 3D concrete printing (3DCP) represents a crucial opportunity for the construction industry to overcome its traditional challenges and embrace a more sustainable, efficient, and transparent future. This systematic review demonstrates that blockchain's ability to provide secure, traceable, and immutable records can address key inefficiencies in construction supply chains and project management. By improving the transparency and accountability of project workflows, blockchain not only enhances stakeholder confidence but also reduces the risk of disputes and delays, both of which are prevalent in traditional construction practices.

In terms of sustainability, blockchain's role in supporting circular economy principles is particularly promising. The ability to track the lifecycle of construction materials through blockchain can facilitate resource optimization, waste reduction, and greater reuse of materials, aligning with the broader goals of sustainable construction. In combination with 3DCP's capacity to reduce waste and improve material precision, blockchain could significantly lower the environmental impact of construction projects, contributing to the industry's long-term sustainability goals.

The application of smart contracts further enhances project efficiency by automating key processes such as payments, procurement, and compliance with regulatory standards. Smart contracts ensure that once specific project conditions are met, actions like payment release or resource allocation can be automatically triggered, minimizing administrative delays and reducing the potential for human error or corruption.

However, despite the theoretical advantages and growing interest in both blockchain and 3DCP, real-world applications remain limited. The review identifies a clear gap in empirical studies and practical implementations that directly examine the intersection of these two technologies. Further research is needed to evaluate blockchain's performance in live construction projects, particularly in how it can scale across different sectors and regions.

In conclusion, blockchain technology presents a significant opportunity to advance the construction industry, especially when combined with 3D concrete printing. The potential for improving sustainability, increasing project transparency, and automating workflows could lead to a new era of more efficient and environmentally friendly construction practices. Future research should focus on real-world applications and case studies to fully realize the benefits of integrating blockchain with 3DCP and broader construction processes.

Author Contributions: Conceptualization, Methodology, Investigation, Software, Formal analysis, Project administration, and Draft preparation was conducted by S.O. Supervision, and Validation was conducted by N.N.

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