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REVIEW

Blockchain-smart contracts for sustainable project performance: bibliometric and content analyses

Mengyuan Cheng[1] · Heap-Yih Chong[2,3] · Yongshun Xu[4]

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Abstract
Blockchain-smart contracts have emerged as a new value proposition in improving certain aspects of sustainability in projects. However, there is little knowledge on how smart contracts can be leveraged to stimulate sustainable project performance from the integrated perspective. This study aims to capture the latest research development and applications of smart contracts for sustainable outcomes throughout the project lifecycle. Bibliometric and content analyses were conducted to critically review smart contracts and sustainable project performance. The results show that various new applications of smart contracts for sustainability have become more popular in the architecture, engineering, construction, and operation (AECO) industry. A smart contracts-sustainable project performance framework has been developed to fill up the research gaps for improving each dimension of sustainability and the integrated dimensions of sustainability during the project lifecycle. This study renders important implications for promoting sustainable project performance in the context of the engineering, construction, and operation industry, particularly for the required interdisciplinary research and practice in smart contracts.

Keywords Critical review · Smart contract · Blockchain · Sustainable project performance · Framework · AECO industry

✉ Heap-Yih Chong
johnchong1983@163.com; heap-yih.chong@curtin.edu.au

Mengyuan Cheng
mengyuancheng1995@163.com

Yongshun Xu
xys8023cm@163.com

1 School of Management, Jilin University, Changchun 130022, China

2 School of Engineering Audit, Nanjing Audit University, Nanjing 211815, China

3 School of Design and the Built Environment, Curtin University, Perth, WA 6845, Australia

4 School of Civil Engineering and Architecture, Hainan University, Haikou 570228, China

1 Introduction

The architecture, engineering, construction, and operation (AECO) industry has always suffered from issues of poor project performance. This is mainly due to the complexity, fragmentation, and low digitization of this industry compared to other industries (Cheng et al., 2020). Multiple participants are required to collaborative enforce the tasks specified in contracts from design to construction, operation, and eventually demolition. Any disruptions would affect project outcomes and even lead to project failure (Martens & Carvalho, 2017). Smart contracts can be considered one of the promising approaches for regulating the delivery process (Chong & Diamantopoulos, 2020) and improving project management (Gouin, 2018), particularly the ability to manage relationships among project partners, enhance transaction transparency, and improve the security of the supply chain (Dal Mas et al., 2020; Yevu et al., 2021). Meanwhile, with the interest of integrating sustainability into project management, organizations have started moving away from economic aspects and consolidating other sustainability requirements from environmental and social aspects (Milner et al., 2019). In this study, this integration describes as sustainable project performance.

Preliminary studies reveal that smart contracts could benefit certain aspects of sustainable project performance. For example, smart contracts can potentially evaluate and alleviate the environmental impact of buildings from the environmental aspect. Wang et al. (2019) proposed a hierarchical framework blockchain-based smart contract for energy demand management to reduce the bad environmental influence of construction. In terms of the social aspect, smart contracts can help solve trust problems, strengthen the working relationship among project participants (Nanayakkara et al., 2019), leading to more effective collaboration (De Filippi et al., 2020), which contributes to sustainable benefits by improving environmental and social performance (Niesten et al., 2017). From the economic perspective, smart contracts can be used to effectively address payment problems, including cash flow problems, contractual disputes, insolvency, and construction delays (Chong & Diamantopoulos, 2020). Smart contracts also can benefit construction information quality management through real-time monitoring and recording of the construction process (Gouin, 2018), thus leading to better time and cost efficiencies.

However, the studies on smart contracts generally address certain issues in each sustainability aspect for improving project performance. Therefore, to understand the updated and new applications of smart contracts for sustainable project performance, this paper aims to answer the following research questions:

- What is the current state of literature on the role and applications of smart contracts for sustainable project performance?
- How do smart contracts contribute to sustainability throughout the project lifecycle?
- What is the future outlook of smart contracts for sustainable project performance?

The first part of the question would be answered through a bibliometric analysis of literature. The second question would be addressed through content analysis that would revolve around various construction stages from economic, environmental, and social perspectives. A proposed framework would solve the third question. The remainder of this paper is organized as follows: the second section discusses the background regarding smart contracts and sustainable project performance; the third and fourth sections present the methods and findings; and the final two sections provide a discussion involving a proposed framework related to applications of smart contracts for sustainable project performance and conclusions, respectively.

2 Background

2.1 Smart contracts

Blockchain technology is described as "a distributed database organized as an ordered list of blocks in which the submitted blocks are immutable" (Casino et al., 2019). In its most basic form, a blockchain is essentially a distributed record database or public ledger that can be used to verify and permanently record transactions between project participants. Each transaction on the blockchain is verified by the consensus of the system participants, thus enabling traceability and security without the need for a central authority (Angelis & Da Silva, 2019). With the characteristics of immutability and decentralization, blockchain is being recognized and adopted in many fields and industries (Nanayakkara et al., 2019; Xu et al., 2022). The evolution of blockchain experiences three stages (Lu, 2019), and it is currently in Stage 2.0, as smart contracts are becoming more popular. Blockchain provides a reliable record carrier and execution environment, as well as it is the most important computing scenario for smart contracts (Zheng et al., 2020). Smart contracts are a piece of executable code that automatically runs on the blockchain to facilitate, verify, or enforce an agreement preset between parties involved in the transaction (Huang et al., 2019). Its advantage lies in the ability to automation execute smart contract clauses when met the coded contractual conditions (Bhatt et al., 2021). Therefore, the project implementation becomes more efficient by improving information management and monitoring and enforcing agreements (Dal Mas et al., 2020). Furthermore, smart contracts also support trust and transparency development in a no-trust contracting environment (Cong & He, 2019) as their immutable execution and record-keeping. Smart contracts thus have become an active value proposition in improving activities efficiency, saving transaction cost, and enhancing project delivery quality (Fernando et al., 2021).

2.2 Sustainable project performance

Sustainable project performance is defined as the performance of all aspects and stakeholders achieved during the projects life cycle (Shen et al., 2016). Understanding sustainable project performance requires considering three essential elements: social, economic, and environmental, where economic performance is about financial performance, environmental performance is about reducing environmental damage and conserving resources, and social performance is about customer and stakeholder well-being (Alhilli & Burhan, 2021). Organizations can achieve higher environmental productivity by reducing air pollution and energy consumption (Elahi et al., 2022a; Zhu et al., 2008), and they also can facilitate effective environmental governance for improving environmental performance (Chardine-Baumann & Botta-Genoulaz, 2014). Besides, studies also recognize the value of construction waste recycling and reuse (Elahi et al., 2022b; Wong & Zhou, 2015) as well as its sustainable land use (Elahi et al., 2021; Zhou et al., 2022). Social sustainability performance is measured in terms of satisfaction with process and results (Li et al., 2019b), value creation for society (Chan & Chan, 2004; He et al., 2019; Hueskes et al., 2017). Studies also emphasize that improving worker occupational health and safety is the main sustainable goal in the engineering, construction, and operation project (Chan & Chan, 2004; Li et al., 2019b). The benefits of sustainability are not just confined to environmental and social benefits; they also enhance organizations' value (Iqbal et al., 2020). Economic aspect of sustainable project performance involves cost, time, and quality in many studies (Li et al., 2019b; Liu et al., 2016). Construction productivity is an important construct of sustainable project performance (Vaux & Kirk, 2018). Empirical evidence also has shown construction productivity be associated with project performance (Odesola, 2015; Soekiman et al., 2011). As a whole, projects should always integrate more sustainability dimensions for upholding sustainable project performance.

3 Methods

Scopus and Web of Science databases were selected for the literature searches because of their broader coverage of quality peer-reviewed papers. We initially considered articles published up to August 2021 for review and supplemented new papers for the final analysis at the beginning of November 2021. The search performed by the authors to obtain literature on the role of smart contracts-sustainable project performance was according to keywords summarized in Table 1. The words were selected based on the dimensions of sustainability and related words. We adopted brainstorming to select related keywords for the initial search because of the diversity of expressing sustainable project performance. However, after several rounds of analyses, the authors confirmed that the selected term of "smart contract" would exclude some important articles. Hence, the "intelligent contract" and "blockchain" were included in the final search and analysis after the "snowball effect" approach of review. This snowballing approach was to avoid missing some keywords as well as to obtain comprehensive review results.

As illustrated in Fig. 1, the initial search resulted in 1968 articles. After eliminating duplicate articles from the sample, only the journal or conference articles written in English were retained; 1863 articles remained for further analysis. After that, two researchers independently carried out the examination and selection of the articles by reading the titles, abstracts, keywords, and the full text of selected articles. The screening was performed based on two inclusion criteria: (a) applications of blockchain and its scope of smart contracts instead of generic blockchain's networks and systems development, and (b) project outcomes for sustainability in the built environment. This data cleaning phase resulted in 82 retained papers, but three articles of this doubtful set were confirmed as "outliers" due to their irrelevancy to the scope of the review. Meanwhile, nine articles were obtained through the subsequent snowballing approach; a total of 88 articles was selected for the final review. The selected articles and their details are presented in Appendix.

The VOSviewer software was used for bibliometric analysis of the selected articles, including annual publication trends, country distribution, high-yielding authors, author cooperation network, and keyword co-occurrence network. Subsequently, we summarized various construction stages from economic, environmental, and social perspectives through content analysis.

Table 1 Set of keywords used in the search for scientific production

Smart contract keywords	Sustainability keywords	AECO keywords
Smart Contract, Intelligent Contract, Blockchain	Sustainability, Sustainable, Performance, Environmental, Environmental Impact, Eco, Environment, Green Emissions, Energy Efficiency, Reverse Logistics, Waste Management, Social, CSR, Sustain, Work Organization, Worker, Corporate Citizenship	Architecture, Engineering, Construction, Operation

4 Findings

4.1 Chronological publication trend

The publication trend of smart contracts-sustainable project performance in the engineering, construction, and operation industry, as shown in Fig. 2. In 2015, the first related paper was published, showing that research on smart contracts-sustainable project performance is in its infancy in this industry. It is clearly observed that the total number of publications of relevant papers has increased significantly since 2008, reaching 35 by 2021. This phenomenon reflects the rising interest of researchers in smart contracts-sustainable project performance. Moreover, the ratio of journal papers to conference papers experienced an inversion in 2021. It may be caused by the Covid-19 limit offline conference that the lower conference paper, while the ongoing number of journal papers shows that academic hotspots and valuable contributions related to smart contracts-sustainable project performance.

4.2 Countries and research institutions

Analysis results show authors of these selected articles came from 32 countries. Table 2 lists the eight most productive countries that contribute 81.82% of the total publications. China ranked first with 16 documents and 109 citations. Australia ranked second with 14 (15.91%) documents and 180 citations (12.86 average citations), followed by UK with 13 (14.77%) and 177 citations (13.62), while the USA ranked fourth with 8 (9.09%) documents and 57 (7.13) citations. The remaining four countries take up 5.35% of publications and 25.67 of citations on average. China, Australia, the UK, and the USA have dominated smart contracts studies. In addition, in these 32 countries, although Luxembourg had only published two articles, its citations were as high as 83 times. Most of the institutions were from developed countries, and only some were from institutions in developing and emerging countries such as China and Turkey.

4.3 Co-occurrence analysis of keywords

The co-occurrence network was described using author keywords. Keywords having the same or comparable meanings, such as “Smart Contract” and “Intelligent Contract” were incorporated. In order to improve the representativeness and comprehensiveness

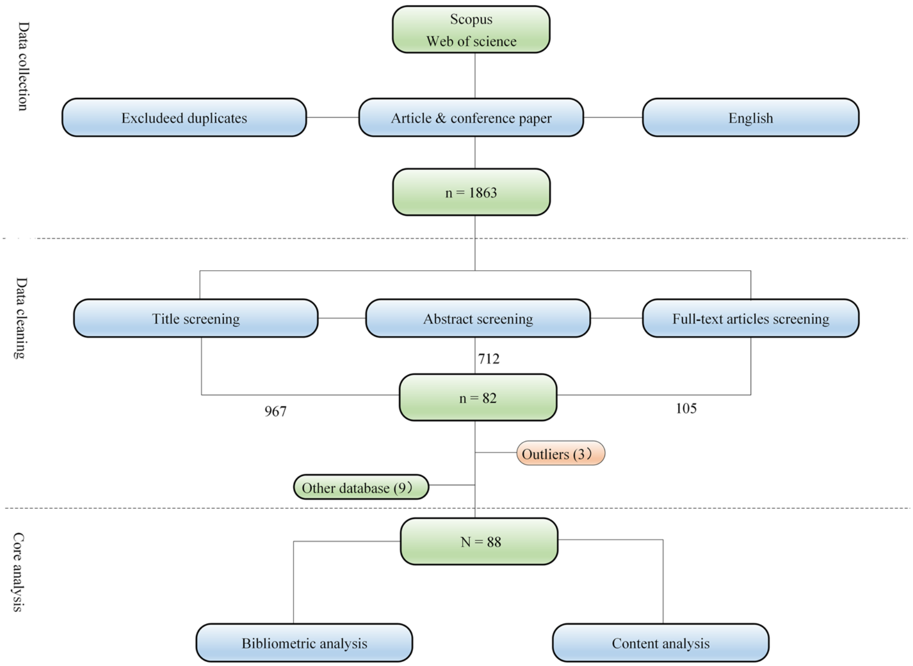

Fig. 1 Overall flow of the review process

of the clustering results, the keyword occurrence threshold was set to 2. As a result, 42 of 170 keywords met the threshold value, as indicated in Table 3.

The 42 keywords were separated into three categories: (a) infrastructure and technologies, both abstract such as blockchain, smart contract and concrete such as Ethereum and Hyperledger Fabric terms, (b) technical features such as trust and decentralization), and (c) particular use cases such as automated payment and quality management. The keywords in the table referred to two major smart contracts application platforms: Ethereum (1.39% in total) and Hyperledger Fabric (0.46%). The most frequently mentioned benefits of using smart contracts were cost (0.93%), followed by decentralization (0.93%), trust 0.69%), and traceability (0.46%). This list of characteristics paints a clear picture of what smart contracts could potentially enable. The keyword analysis also leads to conclusions about potential use cases in the engineering, construction, and operation industry. BIM was mentioned most frequently (5.09%). Other often-mentioned areas were contract management (1.85%), security of payment (1.39%), and supply chain (management) (0.93%).

Figure 3 illustrates the most frequent keywords clustered by co-occurrence. Different colours represent different keyword clusters, and each cluster indicates the relevant association network. The co-occurring keywords were grouped into nine colour-coded clusters. Cluster 1 (yellow), for example, relates to "blockchain", and the primary keywords were "built environment", "digital twin", "IoT", and "SHM".

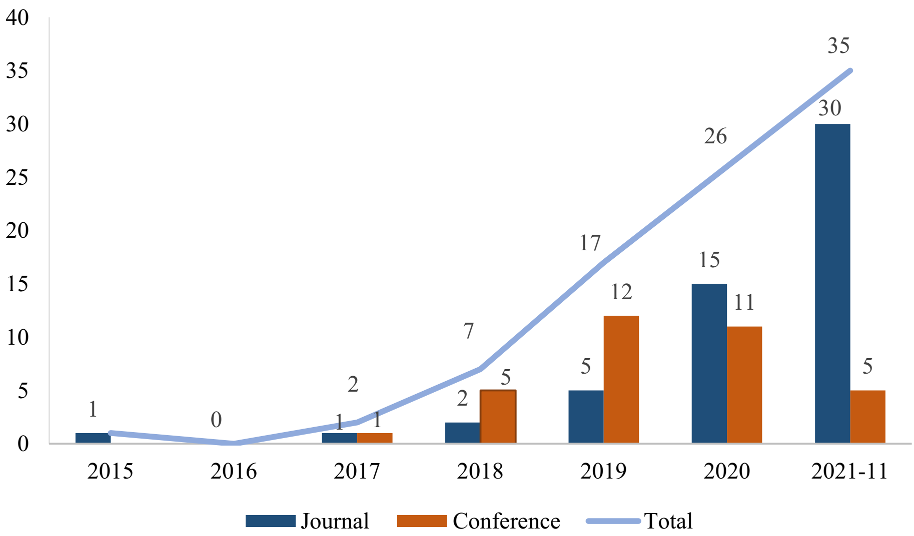

Fig. 2 Paper distribution by year of publication

Table 2 Eight most productive countries of smart contracts studies, 2015–2021

Rank	Country	Number of articles	Percentage	Number of citations	Average citations
1	China	16	18.18%	109	6.81
2	Australia	14	15.91%	180	12.86
3	UK	13	14.77%	177	13.62
4	USA	8	9.09%	57	7.13
5	Italy	8	9.09%	62	7.75
6	Turkey	5	5.68%	39	7.80
7	India	4	4.55%	12	3.00
8	Switzerland	4	4.55%	26	6.50

4.4 Sustainable dimensions

Figure 4 shows the sustainable dimensions over the years. The connection between the economic and social dimensions was the strongest among others. Only the article of Liu et al. (2019) focused on all three dimensions. From the perspective of a single dimension, economic related studies in smart contracts were the most popular trend in the engineering, construction, and operation industry.

5 Applications of smart contracts for sustainable project performance

Content analysis was conducted to understand how smart contracts can support sustainable project performance. Based on the depth and breadth of its concept, we examined which specific applications of smart contracts could support certain sustainable project

Table 3 Distribution of keywords mentioned in the articles

Keywords	Occurrences	%	Keywords	Occurrences	%
Smart contract	64	14.81%	Collaboration	4	0.93%
Blockchain	64	14.81%	Automation	3	0.69%
BIM	22	5.09%	Trust	3	0.69%
Construction industry	15	3.47%	Waste management	3	0.69%
Built environment	12	2.78%	Quality management	3	0.69%
Construction contract	8	1.85%	Automated payment	2	0.46%
Construction	7	1.62%	Construction law	2	0.46%
Security of payment	6	1.39%	Oracles	2	0.46%
Project management	6	1.39%	Construction contract	2	0.46%
Ethereum	6	1.39%	Digital twin	2	0.46%
Advanced technology	5	1.16%	Hyperledger fabric	2	0.46%
Information management	5	1.16%	Distributed energy system	2	0.46%
Distributed ledger	5	1.16%	Traceability	2	0.46%
Sustainability	5	1.16%	Thematic analysis	2	0.46%
Circular economy	5	1.16%	Framework	2	0.46%
Internet of Thing	4	0.93%	Subcontractors	2	0.46%
Cost	4	0.93%	Game theory	2	0.46%
Supply chain management	4	0.93%	Structural Health Monitoring	2	0.46%
Automation construction	4	0.93%	Facilities management	2	0.46%
Digitalization	4	0.93%	Access control	2	0.46%
Decentralization	4	0.93%	Building monitoring	2	0.46%

performance. We first categorized the publications according to the main project stage studied; then, we divided the publications based on applications domain and sustainable project performance and traced their interactions.

Regarding the project stage, we divided it into four categories: (a) architecture stage, (b) engineering and construction stage, (c) operation stage, and (d) multiple stages; we used the indicators of sustainable project performance from the social, economic, and environmental dimensions. The social aspect of sustainable performance is related to safety, health, satisfaction, and value creation. The environmental aspect of sustainable performance includes pollution, use of resources, natural environment, environment management, and green and recycled materials. The economic dimension involves cost, time, quality, and construction productivity. The applications of smart contracts are grouped into three categories at the architecture stage. Contract management, information management, integration management, and supply chain management are the main research theme at the engineering and construction stages. At the operation stages, the application categories are concerned with waste management, maintenance management, and information management. During the multiple stages, smart contracts can be applied in all categories mentioned above.

A Sankey Chart was mapped to capture the applications of smart contracts and sustainable project performance interactions during the project lifecycle, as illustrated in Fig. 5. The height of the bars represents the number of relevant publications. For example, the most active stage of the applications was the engineering and construction stage. Although

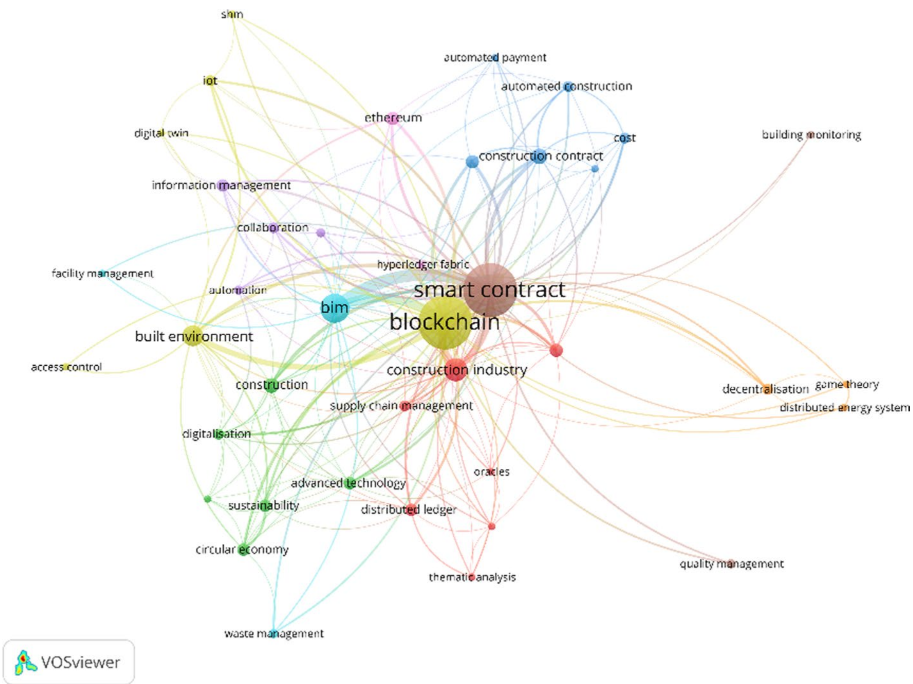

Fig. 3 Keywords co-occurrence network

some studies involved multiple stages, they mainly concentrated on the engineering and construction stage. Furthermore, there were also a few applications of smart contracts at the design stage. For example, Liu et al. (2019) provided a framework by integrating BIM with smart contracts for sustainable building design. The distribution of smart contracts applications across different project phases demonstrates its potential to improve the full project lifecycle.

Various strategies were proposed for achieving sustainable project performance. Cash flow and payments were the most popular practice areas for smart contracts. Besides, other application areas like integration management, contract management, supply chain

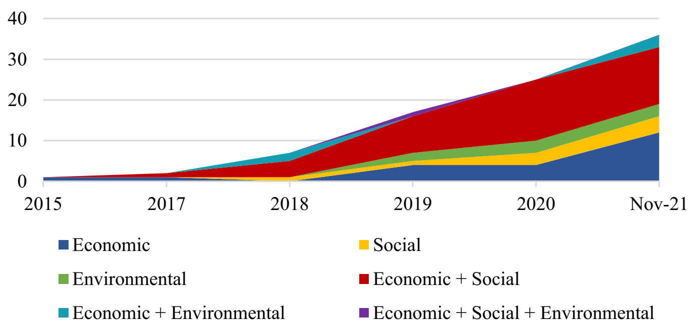

Fig. 4 Evolution of sustainable dimensions over time

management, and information management have also received great attention from academics. One may notice that many studies involved more than one application. By comparing studies published before and after 2015, it reveals that smart contracts applications in construction had become more diverse, while several applications only published no more than two papers, such as green design, bidding management, safety management, and emergency management. Irrespective of the applications of smart contracts, the economic dimension of sustainable project performance received the most attention (46.9%), closely followed by social (43.9%) and environmental (9.2%) dimensions. The interactions were further disaggregated when most publications involved more than one dimension of sustainable project performance. For instance, most of the publications with an economic focus would also relate to the other dimensions of sustainable project performance. Overall, most publications (57.9%) had discussions relevant to at least two dimensions of sustainable project performance. In sum, discussions on smart contracts with sustainable project performance are multidimensional, indicating that the dimensions of sustainable project performance cannot be examined in isolation from each other.

5.1 Applications of smart contracts for sustainable project performance at the architecture stage

Smart contracts mainly serve as information management at the architecture stage. For example, Nawari and Ravindran (2019) presented an integrated BCT and BIM architecture to improve the permission process and post-disaster recovery operations. A ring signature was integrated with smart contracts for project review, which could realize the fairness and impartiality of grid project review (Nie & Liu, 2021). Bennett et al. (2021) presented the potential applications of smart contracts for the specific land dealings inherent to land administration. This facilitates making optimal decisions about land use, thereby improving social, economic, and environmental sustainability. Furthermore, smart contracts can assist in design analysis and optimization, critical at the early or pre-design stage of

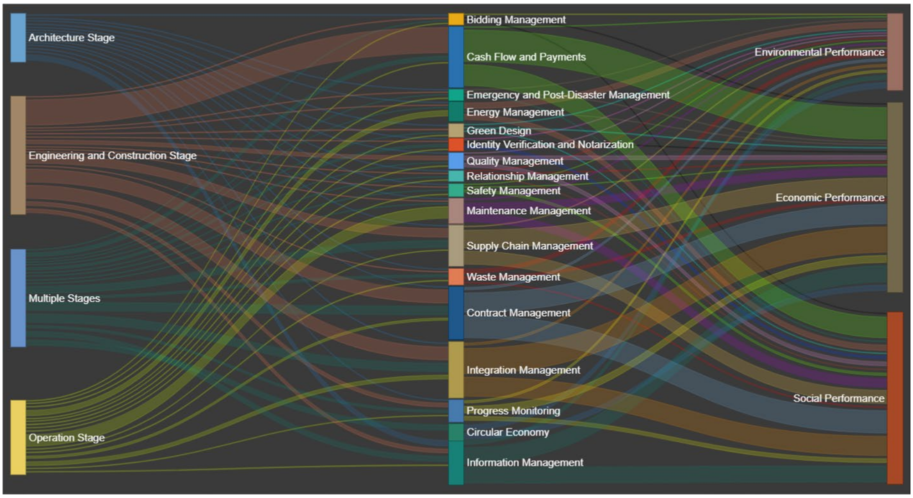

Fig. 5 Sankey Chart and overview of smart contracts-sustainable performance during the project lifecycle

establishing a sustainable building design. Besides, smart contracts have a record value exchange function (Kim & Laskowski, 2017). Smart contracts can solve the potential challenges by recording and verifying the sustainability information of the materials set in the BIM tool throughout the design process (Liu et al., 2019). Overall, these applications have the great potential and ability to uphold the integrated sustainability dimensions for sustainable project performance, especially when smart contracts have been designed and implemented at the beginning stage of project development.

5.2 Applications of smart contracts for sustainable project performance at the construction stage

The economic aspect of sustainability has been the main agenda during the construction stage. Smart contracts can aid in automated procurement transactions, which will significantly decrease exchange and transaction costs. Other benefits of smart contracts include eliminating third parties, reducing administrative costs, avoiding partners from exceeding payment deadlines, and increasing productivity and trust (Ahmadisheykhsarmast & Sonmez, 2018). These benefits are mainly due to smart contracts' functions for quick approval and tracked payment transactions under a confidential and efficient payment environment at this stage (Cardeira, 2015). Besides, smart contracts can capture process information at any point and record quality information in construction projects (Gouin, 2018), especially from inventory management and timely identification of the party responsible for the quality defects or wastage (Sheng et al., 2020a).

Effective monitoring is critical for project success, especially in complex projects. Another key use of smart contracts in construction management is monitoring construction progress, which gives real-time, trustworthy information about the entire construction process (Gouin, 2018). During the fabrication stage, the integration of BIM, DLT, and IoT can automatically monitor the progress of the installation activity to speed up the payment authorization process and improve the relationship (Li et al., 2019a). To support quality compliance inspection, Sheng et al. (2020b) established a quality acceptance model to lower the application threshold of smart contracts.

Apart from that, other studies highlighted their potential in improving the social aspect of sustainability from the perspective of collaboration among stakeholders. For example, Danielle (2020) discussed that smart contracts could enable stakeholders to collaborate on management practices and thus enhance the efficiency of PPPs. Furthermore, Calvetti et al. (2020) investigated and disclosed the key challenges faced in the ethical implementation of workforce monitoring/performance evaluation using smart contracts in a Construction 4.0 environment. Moreover, through round-table conversations, Nanayakkara et al. (2019) investigated stakeholders' perspectives on deploying blockchain and smart contracts in the construction sector. Koç and Gürgün (2020) explored the driving factors for construction partners to adopt smart contracts. These studies are vital for contributing to sustainable social performance as they have the potential to identify any beneficial or detrimental relationships that occur in the process, which can affect the collaborative relationships between project team members.

5.3 Applications of smart contracts for sustainable project performance at the operation stage

Smart contracts have been actively integrated with other emerging technologies at the operation phase. The applications of smart contracts would provide secure private data storage and enhance operational safety and efficiency. They have a great potential in fulfilling all sustainability dimensions for sustainable project performance at this stage. For example, Niya et al. (2018) designed and implemented an automated and decentralized pollution monitoring system for automatic monitoring of water and air quality in the environments. Jo et al. (2018) improved information sharing and data security by integrating IoT with smart contracts for structural health monitoring. Seghezzi et al. (2020) supported that integrating BIM and smart contracts provides relevant advantages for building, increasing network security, reliable data storage, and ensuring traceability. Some similar applications have been discussed to help monitor maintenance information with higher reliability and automatic instructions (Bindra et al., 2019; Li et al., 2020; Moretti et al., 2021; Pradhan & Singh, 2021). Moreover, smart contracts also are utilized to efficiently control and use energy in buildings through automated energy trading processes (Botsaris et al., 2021; Li et al., 2019c; Masaud et al., 2020).

5.4 Applications of smart contracts for sustainable project performance across the stages

Smart contracts have been used in more than one of the previously described stages. The functions of smart contracts can overlap between design and construction, or even can be applied throughout a whole building lifecycle. For example, smart contracts-based payment system can be applied to multiple stages for all business operations. In the construction industry, some novel smart-contract-payment-security systems have been developed at the design stage and implemented at the construction stage to eliminate or reduce payment problems in construction projects (Ahmadisheykhsarmast & Sonmez, 2020; Nanayakkara et al., 2021).

Besides, smart contracts can integrate with a circular economy across the stages. This can be achieved through the built environment's complete material and energy traceability (Shojaei et al., 2021), which will help reduce transaction costs, enhance performance and communication along the supply chain, ensure human rights protection and welfare, and reduce carbon footprint (Upadhyay et al., 2021). For example, Akbarieh et al. (2020) proposed that smart contracts can be used in synergy with BIM for end-of-life phase material disposal. This framework creates a secure and automated exchange of lifecycle information among engineering, construction, and operation participants, creating financial value that benefits all members of society together, while improving sustainability and circularity in the construction sector. Although the start-up cost could be an issue when considering this technology with circular economy, its pros would surpass cons throughout the process (Di Vaio et al., 2023).

Smart contracts can also be applied to trace the quality of information throughout the project lifecycle. Hunhevicz et al. (2020) designed an incentive system based on smart contracts and confirmed that this system could incentivize high-quality datasets in the design bid build process and transform subsequent procurement processes. Overall, smart contracts are also a platform for communication and interaction management, as it creates an appropriate platform for archiving all project-wide communications and act as information management, claims management, and knowledge management system.

6 Discussion and framework

The bibliometric and content analyses have uncovered new scientific inquiries and useful insights into the gaps between smart contracts and sustainable project performance. A research framework is then proposed to link current research development with the gaps and future needs, as illustrated in Fig. 6.

The first core component of the framework is the applications of smart contracts in different sustainability dimensions that support sustainable project performance. The review findings reveal that smart contracts have economic benefits and could simultaneously achieve environmental and social performance. For example, the ability to automatically execute smart contracts supports the formulation of an effective green design, thereby benefiting a series of construction activities. The use of smart contracts in progress monitoring and quality management positively impacts stakeholder satisfaction and operating costs. In the multiple stages, the applications of smart contracts have resulted in improved economic and social sustainable performance through enhanced cost-saving, schedule optimization, quality improvement, safety improvements, and relationship development, especially through integrating smart contracts with other technologies. Although smart contracts can support different sustainability aspects, the multidimensional link between smart contract applications and sustainable project performance has not yet been established. New applications of smart contracts in conjunction with more sustainable domains require additional attention and development in research and practice—for example, the link between contract management and sustainable performance, especially environmental performance. Through performance-based contracts implemented in the built environment, services can align incentives with the lifecycle of the building, thereby benefiting the environment.

The second component of the framework is the management areas of smart contracts used at the specific project phases. The study has found that contract management, information management, supply chain management, facilities management, and integration management are used with specific objectives for improving project performance. For example, using smart contracts to cash flow and payments is a key management strategy for improving the economic aspects of sustainable performance. Maintenance management during the operations phase is the main strategy used by smart contracts to improve environmental performance. Besides, the application of smart contracts to green sustainable design has a direct effect for enhancing environmental sustainability. The framework also suggests specific best matches between smart contract-based applications and management strategies at specific project stages, which project managers could refer to in achieving their projects' specific goals. Particularly regarding information management, smart contracts can support the development of a safety management system framework to improve the health and safety performance of construction projects (Hirani et al., 2019). Moreover, smart contracts can also assist in green building design and construction through record storage and self-execution (Liu et al., 2021), which is expected to improve the environmental performance and productivity of projects. Some opportunities also exist in the construction supply chain (Groschopf et al., 2021; Yevu et al., 2021), which can significantly lift economic, environmental, and social performance.

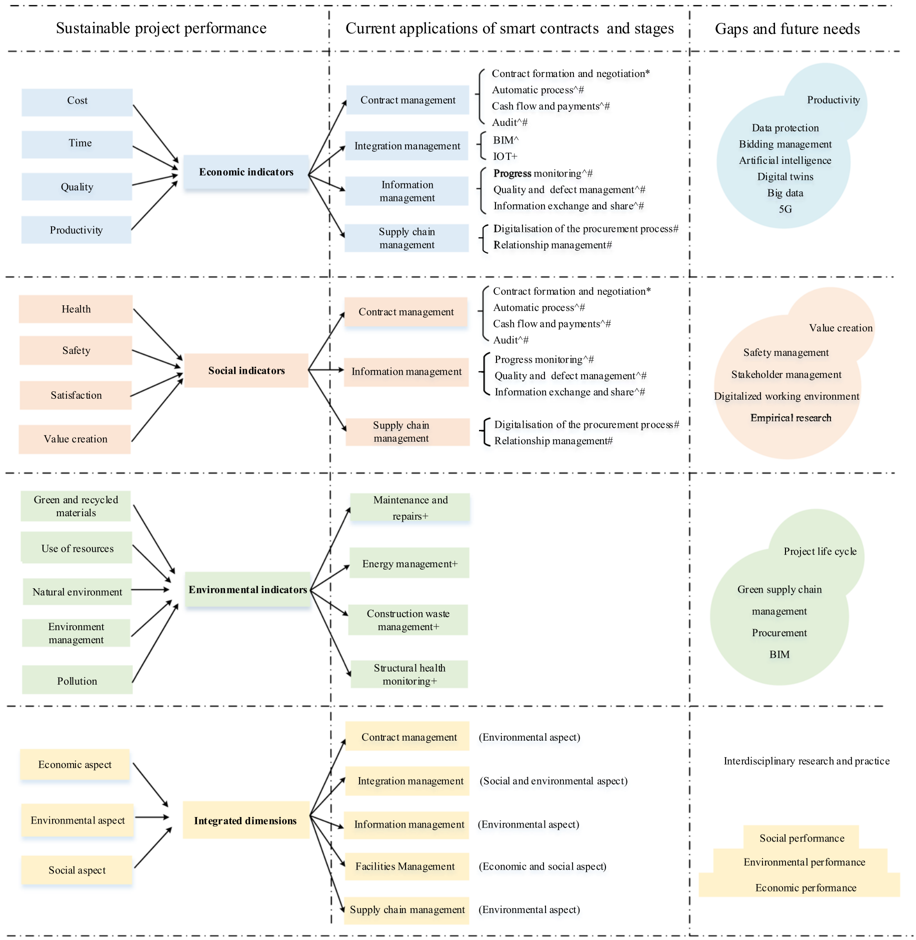

Fig. 6 Research framework of smart contracts for sustainable project performance. *Design Stage, #Construction Stage, + Operation Stage, ^Across Stages

Research gaps and future research is the third significant component of the framework. It highlights the need for interdisciplinary research and practice in smart contracts across the sustainability dimensions. First, smart contracts can integrate with bidding management to unleash a greater impact on economic sustainability that would have influenced a series of subsequent activities such as procurement, production, and construction. Furthermore, the project subject has changed in the digital work environment: from focusing only on self-interest to multi-stakeholders (Cova & Salle, 2005). These shifts have led to a refocusing of project management objectives in the interests of multi-stakeholders, whether these groups of participants are internal or external to the organization (Caldwell et al., 2017). Therefore, the discourse connecting smart contracts and social performance through stakeholder management will be the future need in the digitalized working environment. Most current studies on smart contracts and social performance are based on theoretical analyses. Empirical studies are required to investigate the future trust and collaborative relationships among stakeholders in smart contracts (Kassen, 2021). In addition, scholars have also found various green opportunities across the supply chain (Chang et al., 2019) as well as BIM through its facilitation of green design (Chong et al., 2017) to improve environmental sustainability performance. Therefore, integrating smart contracts and BIM into the green delivery process requires further exploration in project management, which will involve cross-disciplinary research and practice. The integration of smart contracts with BIM improves resource efficiency (Shojaei et al., 2019), which leads to a reduction in material and energy consumption. It has also been found that the integration of smart contracts and IoT can improve transparency and trust (Dustdar et al., 2021), thereby bringing greater stakeholder satisfaction. As a result, these emerging technologies, including Artificial Intelligent, digital twin, and 5G, should be considered with smart contracts in future research development.

Moreover, some sustainable project performance indexes require to be systematically developed in association with smart contracts, for example, productivity and value creation. Similar research needs to be explored to investigate the potential of smart contracts to help in the efforts to improve productivity. Social value creation is viewed as a critical factor for social benefits (Kassen, 2021). In future studies, empirical studies and case analyses can be conducted to explore the role of smart contracts in social value creation. Last but not least, there is a lack of in-depth research on smart contracts as the main approach in managing projects. For example, do smart contracts help build cumulative capacities for managing economic, environmental, and/or social performance? Thus, a practical sand-cone model for smart contract's ability still needs to be developed and empirically proven to further uphold sustainable project performance in the engineering, construction, and operation industry.

7 Conclusions

This paper has captured the state-of-the-art development and applications of smart contracts for sustainable project performance. The results show the applications of smart contracts have a great prospect for enhancing sustainable project outcomes. Several key research themes in smart contracts have been uncovered for supporting and improving project sustainability performance throughout the project lifecycle. From the design stage, smart contracts can be used for sustainable design analysis and optimization, information management, thus reducing negative environmental impacts and improving overall project efficiency and performance. In terms of the construction stage, smart contracts can formulate new and automatic approaches in contract management, information management, and stakeholder management, thus improving the relationship between project partners, cost savings, materials efficiency, and overall health and safety. For the operation stage, the value of smart contracts lies in providing real-time monitoring and facilities management.

This paper contributes to identifying valuable areas for the research development of smart contracts for sustainability, which will help researchers in obtaining and understanding the hot spots and research trends as a whole. The second contribution of the paper is the research framework, which has revealed new and insightful perspectives for addressing and promoting practical ideas for the overall sustainable project performance in the engineering, construction, and operation industry, particularly for the interdisciplinary research in smart contracts for accommodating sustainability needs in projects. Future directions and research gaps have also been articulated to meet the sustainability needs of the industry.

This could help bridge the gap between academia and practice in providing sustainable benefits by smart contracts.

Nevertheless, some limitations exist in this study. First, although the findings and analyses were based on 88 papers in this area of research, the practical implications of these papers are still quite limited, with very little research work on sustainable project performance. Second, the inclusion of "intelligent contract" and "blockchain" in the final search needs to be interpreted and checked carefully as most of them were not related to smart contracts and errors may happen in the analysis. Third, the proposed framework may be dynamic and can be extended with the increasing depth of smart contract applications.

Appendix: Characteristics of selected articles

No	Author	Source type	Application stage	Main sustainability dimension				
			A	EC	O	ECO	SOC	ENV
1	Altay and Motawa (2020)	Journal	•	•		•	•	
2	Li et al. (2020)	Conference			•	•	•	
3	Sen Gupta et al. (2021)	Journal			•			•
4	Masaud et al. (2020)	Journal			•			•
5	Chang et al. (2021)	Journal			•	•		
6	Nagothu et al. (2018)	Conference		•		•		
7	Li et al. (2019a)	Conference	•	•	•	•		
8	Nie and Liu (2021)	Journal	•			•		
9	Ahmadisheykhsarmast and Sonmez (2020)	Journal	•	•	•	•		
10	Owusu et al. (2020)	Conference	•	•	•	•	•	
11	Gurgun and Koc (2021)	Journal	•	•	•	•	•	
12	Danielle (2020)	Journal	•	•	•		•	
13	Shojaei et al. (2019)	Conference		•		•		
14	Çevikbaş and Işık (2021)	Journal	•	•	•	•	•	
15	Li and Kassem (2021)	Journal	•	•	•	•		
16	Sigalov et al. (2021)	Journal		•		•		
17	McNamara and Sepasgozar (2018)	Conference	•	•	•	•	•	
18	Mason (2019)	Journal		•	•	•		
19	Seghezzi et al. (2020)	Conference			•	•		
20	Nawari and Ravindran (2019)	Journal	•			•	•	
21	Nanayakkara et al. (2021)	Journal	•	•	•	•		
22	Hewavitharana et al. (2019)	Conference	•	•	•	•	•	
23	Tiwari and Batra (2021)	Journal	•	•	•	•	•	
24	Abdallah et al. (2019)	Conference			•		•	
25	Xu et al. (2021)	Journal	•	•	•		•	
26	Upadhyay et al. (2021)	Journal		•	•		•	
27	Wang et al. (2019)	Conference			•			•
28	Ongena et al. (2018)	Conference		•	•			•
29	Liu et al. (2019)	Journal	•			•	•	•

No	Author	Source type	Application stage	Main sustainability dimension				
			A	EC	O	ECO	SOC	ENV
30	Calvetti et al. (2020)	Journal		•		•		
31	Çetin et al. (2021)	Journal		•		•		•
32	Singh et al. (2021)	Conference		•		•		
33	Luo et al. (2019)	Conference	•	•	•	•	•	
34	Hamledari and Fischer (2021b)	Journal		•			•	
35	Sheng et al. (2020a)	Journal		•		•	•	
36	Bindra et al. (2019)	Conference			•	•	•	
37	Niya et al. (2018)	Conference			•	•		•
38	Leka et al. (2019)	Conference			•	•	•	
39	Li et al. (2019c)	Journal			•			•
40	Udokwu et al. (2021)	Conference	•			•	•	
41	Botsaris et al. (2021)	Journal			•			•
42	McNamara and Sepasgozar (2020)	Journal	•	•	•	•	•	
43	Hunhevicz et al. (2021)	Journal	•	•	•	•		
44	Pellegrini et al. (2020)	Journal	•	•	•			•
45	Pattini et al. (2021)	Conference		•		•	•	
46	Yevu et al. (2021)	Journal	•	•	•	•	•	•
47	Koç and Gürgün (2020)	Journal	•	•	•		•	
48	Shojaei et al. (2021)	Journal	•	•	•	•		•
49	Scott et al. (2021)	Journal		•		•		
50	Götz et al. (2020)	Journal			•	•	•	
51	Lu et al. (2021)	Journal	•	•	•	•		
52	Akbarieh et al. (2020)	Conference			•			•
53	Sheng et al. (2020b)	Conference		•		•	•	
54	Ye and König (2020)	Conference		•		•	•	
55	Bennett et al. (2021)	Journal	•			•	•	
56	Jo et al. (2018)	Journal			•		•	
57	Hunhevicz et al. (2020)	Conference	•	•		•	•	
58	Okangba et al. (2021)	Conference	•	•	•	•	•	
59	Li and Kassem (2019)	Conference	•	•	•	•		
60	Chong and Diamantopoulos (2020)	Journal	•	•	•	•	•	
61	Ye et al. (2020)	Conference	•	•	•	•	•	
62	Ciotta et al. (2021)	Journal		•		•	•	
63	McNamara and Sepasgozar (2021)	Journal	•	•	•	•	•	
64	Mason (2017)	Journal	•	•		•		
65	Moretti et al. (2021)	Journal			•	•	•	
66	Li et al. (2021)	Journal			•			•
67	Antonino et al. (2019)	Journal			•	•	•	
68	Wu et al. (2021)	Journal		•		•		
69	Yang et al. (2020)	Journal	•	•	•	•	•	
70	Hamledari and Fischer (2021c)	Journal	•	•	•	•		
71	Faraji (2019)	Conference	•	•	•	•	•	
72	Cardeira (2015)	Conference	•	•	•	•		

No	Author	Source type	Application stage	Main sustainability dimension				
			A	EC	O	ECO	SOC	ENV
73	Dounas et al. (2020)	Conference	•	•	•		•	
74	Gouin (2018)	Journal		•		•	•	
75	Mason and Escott (2018)	Conference	•	•	•	•	•	
76	Pradhan and Singh (2021)	Journal			•	•		
77	Ahmadisheykhsarmast and Sonmez (2018)	Conference		•		•	•	
78	Nanayakkara et al. (2019)	Conference	•	•	•	•	•	
79	Badi et al. (2021)	Journal	•	•	•	•	•	
80	Salleh et al. (2020)	Journal	•	•	•	•	•	
81	Hamledari and Fischer (2021a)	Journal	•	•	•	•	•	
82	Cardeira (2017)	Conference	•	•		•	•	
83	Zhang et al. (2020)	Journal		•		•	•	
84	Mohammed et al. (2021)	Journal		•		•	•	
85	Hargaden et al. (2019)	Conference	•	•	•	•	•	
86	Di Giuda et al. (2020)	Conference	•	•	•	•	•	
87	Narayan and Tidström (2020)	Journal		•		•		•
88	Chaveesuk et al. (2020)	Conference	•	•	•		•	

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Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

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