APPLICATION OF BLOCKCHAIN IN PROCUREMENT AND MANAGEMENT OF BUILDING SERVICES: A CRITICAL AND SYSTEMATIC REVIEW

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SUMMARY: Building services systems are essential for creating a comfortable and safe living environment in buildings. These are complex systems with high stakeholder involvement, a lengthy lifecycle, and high financial costs. This leads to building services systems having complex procurement and management (P&M) requirements which create a multitude of challenges. Blockchain technology has emerged as a revolutionary digital technology under "Procurement 4.0". The purpose of this paper is to investigate the applicability of blockchain technology for systematic procurement and management of building services. The science mapping method was used to systematically and quantitatively analyse 102 publications related to bibliographic records retrieved from Scopus and the Web of Science databases. This includes content analysis of the existing issues, current trends of technologies, and applicability of blockchain in the P&M of building services. The results of the bibliometric analysis indicate that publications had grown significantly faster in 2021 related to the P&M of building services with new technologies while there is a minimal collaboration of countries, organisations and authors in publishing research in this area. Further, it is observed that Building Information Modelling (BIM) is the main technology utilised in general P&M. As a result of content analysis, a total of 28 issues that affect the performance of procurement and management of building services are identified. The paper critically evaluates blockchain technology in terms of peer-to-peer networks, hashing algorithms, public key cryptography, consensus mechanisms, smart contracts, and distributed ledger. It indicates that blockchain provides a perfect match for resolving these issues. The findings of the research will open a path to apply blockchain technology in building services. The study offers a readily available point of reference for practitioners, policymakers and research and development bodies.

1. INTRODUCTION

Building services systems are essential for the functioning of a built asset and are responsible for making buildings habitable, comfortable, and safe. Although there are few building service items defined in a Bill of Quantities (BOQ) of a construction project, their cost component is significantly higher. They usually make up 15% to 60% of the total construction cos ts (Chauhan et al., 2022) and a maximum of 50% of the total project duration (Wu et al., 2022b). Thus, the financial feasibility of a construction project is highly sensitive to the installation of building service systems.

However, unlike other resources, building service systems have complex procurement and management requirements (Marsh Christopher, 2012). In this study, "Procurement and Management (P&M) of Building Services" refers to all the operations of building service systems from planning to maintenance and disposal. The traditional procurement and management processes adopted for building services systems are time-consuming, expensive, and tend to contain significant human errors (Hewavitharana et al., 2019). The total negative economic impacts of poor procurement practices in Australia are estimated at around $239 million per annum (Deloitte Access Economics, 2015). Currently, there are no unified systems that even support all construction procurement processes and data exchanges (Perera, 2021). For example, Building Information Modelling (BIM) enhances the transferring and managing of information related to designs but not procurement issues (Teo et al., 2022). Building service engineers and other professionals face challenges in the procurement and management of building services systems due to the lack of transparency, absence of trust, incompatibility of designs and specifications, miscommunication, and traceability (Rabb and Vesali, 2022, Xu et al., 2021).

Construction procurement and management is an area that can benefit from the adoption of new technologies (Perera et al., 2021c). Building services are a major element in construction projects, and the adoption of technology in the procurement and management of building services systems is critical. There is limited research in this area hence it creates a knowledge gap on how digital technologies can solve issues related to P&M of building services. This study aims to conduct a systematic literature review (including bibliometric and content analysis of literature) on the procurement and management of building services. The following objectives were identified to achieve the aim of the research.

1. To identify the existing issues of procurement and management of building services

2. To identify the technologies that are trending in the application of procurement and management in general

3. To establish the potential of blockchain in resolving issues related to procurement and management of building services

The rest of the paper is organised in the following order: The methodology adopted for the study is presented in Section 2. Section 3 addresses the results and discussion. It includes the bibliometric analysis and content analysis on existing issues of procurement and management of building services, current trends of technologies, blockchain technology and the potential of blockchain technology to address the procurement and management issues in building services. Lastly, the conclusion together with the practical implication of the research and recommendations for further investigation possibilities are presented in Section 4 of this paper.

2. RESEARCH METHODOLOGY

This study is grounded on a systematic review of the literature that focuses on the previous research on procurement and management of building services. This involves an initial search for literature using several databases, filtration of the process as well as analysing the content of the identified literature. (Briner and Denyer, 2012). In the first stage, a search for the literature was conducted using two databases, including Scopus and Web of Science compliant with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guideline (Page et al., 2021). In the second stage, relevant papers were filtered systematically. In the final stage, a detailed review was carried out. The subsequent sub-sections comprehensively elaborate on the three stages utilised in this study.

2.1 Literature search

The initial search was carried out using the Scopus database. Scopus was selected due to its wider encompassing range compared to alternative databases such as Google Scholar, PubMed, and Science Direct (Osei-Kyei and Chan, 2015). Further, Elsevier's Scopus database is a better performer in terms of tracing when compared to above mentioned other databases (Zhao et al., 2019, Osei-Kyei and Chan, 2015). To get a substantial number of papers, a comprehensive search was conducted using the keywords with appropriate Boolean operators: ("Procure*" OR "Tender*") AND ("Digital Technologies" OR "Blockchain" OR "BIM" OR "Building Information Modelling" OR "Industry 4.0") AND ("Construction" OR "Built Environment" OR "Building services" OR "MEP" OR "Mechanical" OR "Electrical" OR " Plumbing" OR "Structure*" OR "Architecture*" OR "Civil Engineering" OR "Construction Engineering" OR "Construction Industry" OR "Construction Management" OR "Construction Engineering and Management") with no limitation in terms of the year (searched on 18 August 2023). 579 papers were retrieved from the Scopus databases after this initial literature search.

In addition to Scopus, the literature search was carried out using the Web of Science (WOS) database to verify all the relevant papers were captured and to ensure that an acceptable number of research papers were used in this study. However, Web of Science database search results produced a significant number of out-of-scope papers compared to the Scopus database. Therefore, an advanced search string was used without changing the scope of search in WOS database; TS= (("Procure*" OR "Tender*") AND ("Digital Technologies" OR "Blockchain" OR "BIM" OR "Building Information Modelling" OR "Industry 4.0") AND ("Construction" OR "Built Environment" OR "Building services" OR "MEP" OR "Mechanical" OR "Electrical" OR " Plumbing" OR "Structure*" OR "Architecture*" OR "Civil Engineering" OR "Construction Engineering" OR "Construction Industry" OR "Construction Management" OR "Construction Engineering and Management")). 264 publications were filtered from the Web of Science database after the initial search.

2.2 Selection of relevant papers

Only peer-reviewed journal articles were included in the study to ensure the credibility and authenticity of publications. It is worth noting that conference papers, book chapters and non-academic or non-peer-reviewed domains such as reports, websites, forums, discussions etc. were excluded to confirm the rigour of the systematic review (Santos et al., 2017). The study also restricted the language type to the English language based on the study's aim and objectives. At the end of the initial search, 232 and 157 publications were selected from Scopus and Web of Science databases respectively. Then, all the publications retrieved from Scopus and Web of Science were exported to an Excel file separately. A total of 247 publications were identified after comparing two databases while removing 142 duplicates. Subsequently, a careful analysis of the "Article title/Abstract/Keyword" fields was carried out and only 102 publications were selected. This analysis was based on the scope of the study. For instance, articles related to "BIM and the energy consumption of buildings" were removed as they were out of the scope of the study. Additionally, articles related to technology such as IoT, AI etc which were associated with construction but not relevant to procurement and management, were also eliminated as they were beyond the study's scope.

2.3 Detailed review

A detailed review was conducted based on the existing issues of procurement and management of building services, technologies used in general procurement and management and blockchain technology. Based on the detailed review, the application of blockchain technology in the procurement and management of building services was proposed. The overview of the literature review and research process is mentioned in Figure 1.
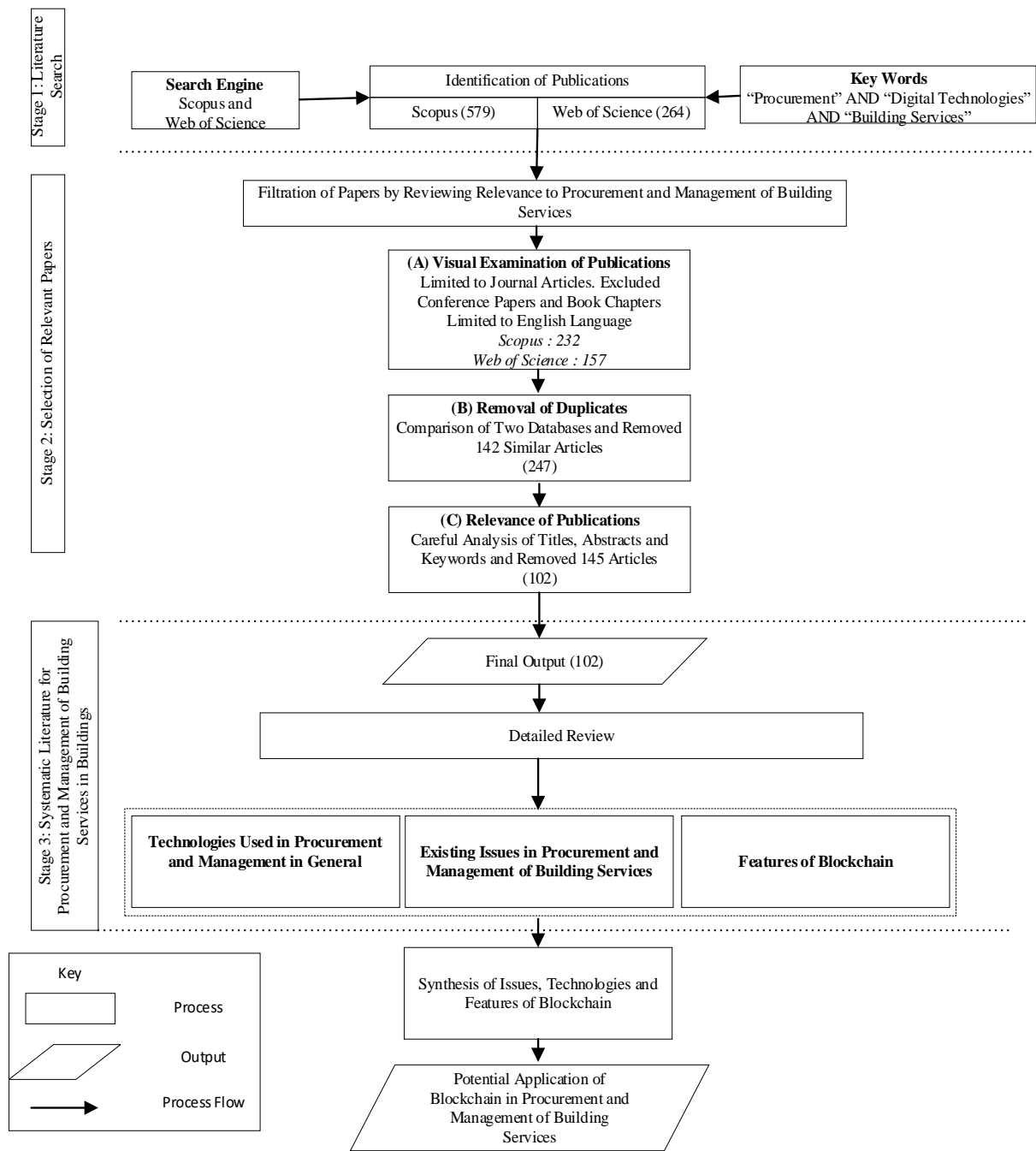
Stage 1: Literature Search

Search Engine
Scopus and
Web of Science

Identification of Publications
Scopus (579) | Web of Science (264)

Key Words
"Procurement" AND "Digital Technologies"
AND "Building Services"

Stage 2: Selection of Relevant Papers

Filtration of Papers by Reviewing Relevance to Procurement and Management of Building Services

(A) Visual Examination of Publications
Limited to Journal Articles. Excluded
Conference Papers and Book Chapters
Limited to English Language
Scopus : 232
Web of Science : 157

(B) Removal of Duplicates
Comparison of Two Databases and Removed
142 Similar Articles
(247)

(C) Relevance of Publications
Careful Analysis of Titles, Abstracts and
Keywords and Removed 145 Articles
(102)

Stage 3: Systematic Literature for Procurement and Management of Building Services in Buildings

Final Output (102)

Detailed Review

Technologies Used in Procurement and Management in General

Existing Issues in Procurement and Management of Building Services

Features of Blockchain

Synthesis of Issues, Technologies and Features of Blockchain

Potential Application of Blockchain in Procurement and Management of Building Services

Key
Process
Output
Process Flow

Figure 1: An Overview of the Literature Review and Research Process.

3. RESULTS AND DISCUSSION

This section comprised the results and discussion of bibliometric analysis and content analysis of the study.

3.1 Chronological publication trend

Figure 2 demonstrates the publication trend of related research on the procurement and management of building services. Although the time limit is not set, the first related paper emerged in 2010. However, only a very limited number of publications can be seen in 2010. A considerable number of publications started publishing in 2021.
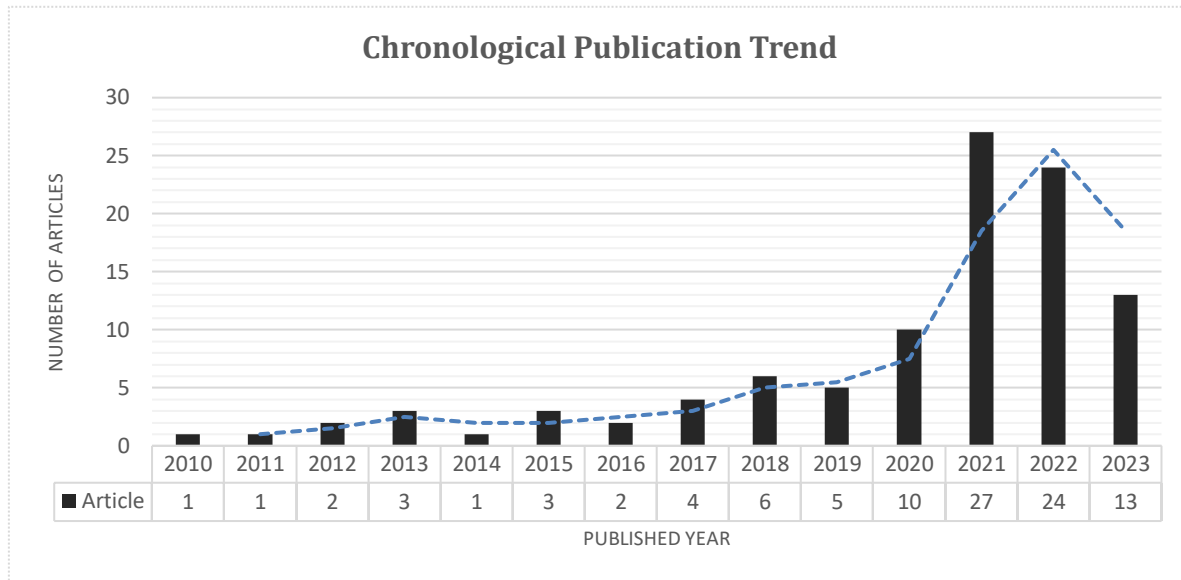

Figure 2: Chronological Publication Trend.

It can be found from the trend lines that journal papers have been developing rapidly in the last three years. Among them, 27 were published in 2021, and 24 publications were published in 2022. However, 13 publications were published as of 23 August 2023 related to procurement and management in building services. This implies a positive trend for 2023 regarding digital technologies in the procurement and management of building services. The number of journal papers had grown significantly faster in 2021 indicating that research has become more established and popular in academia. Further, 102 publications are from journal articles reflecting a wide variety of multidisciplinary sources. Of these, five journals have published more than 4 publications related to the topic such as Automation in Construction, Sustainability, Applied Sciences, Journal of Construction Engineering and Management, and Journal of Cleaner Production while the rest of the publications are limited to one or two with other journals.

3.2 Analysis of collaborative networks of authors, institutions and countries

A network of international scientific collaborations helps to recognise the countries that are actively engaged in the relevant research area. To discern these countries and recognise the most influential ones, and their collaborative relationships, a network was established utilising VOSviewer 1.6.19 software. "coauthorship", was selected as the type of analysis and "countries" was selected as the unit of analysis. Further, the counting method was selected as "fractional counting". The "minimum number of documents of a country" and the "minimum number of citations of a country" were both placed to 3, for achieving the optimum network. Of the 48 countries identified, 13 met the threshold and were included in the resultant network. In Figure 3, each node represents a country, and its size reflects the number of papers contributed by authors from that country related to procurement and management of building services. The majority of the publications focused on Australia, China, India, the

United Kingdom (UK) and Malaysia including 14, 13, 12, 11 and 9 publications respectively. This indicates that most of the publications related to procurement and management of building services are carried out by developed countries. However, it is noticed that in recent years developing countries are also trying to adopt digital technologies in operation and this finding establishes that countries like India and Malaysia are more in to research regarding the digitalisation of construction. Systematic procurement and management for building services contribute to developed countries to complete projects very effectively and efficiently. For instance, in Australia, it is estimated that improved procurement can save the costs of rectifying design errors in construction $87 million (Deloitte Access Economics, 2015). Links in Figure 3 denote the collaboration between countries, and their thickness explains the collaboration strength between the two countries. For example, Australian researchers have established a network of collaboration with sight countries across the world, followed by the United Kingdom with seven countries. This indicates that Australia has the highest number of publications having more collaboration with other countries when publishing papers in this area.
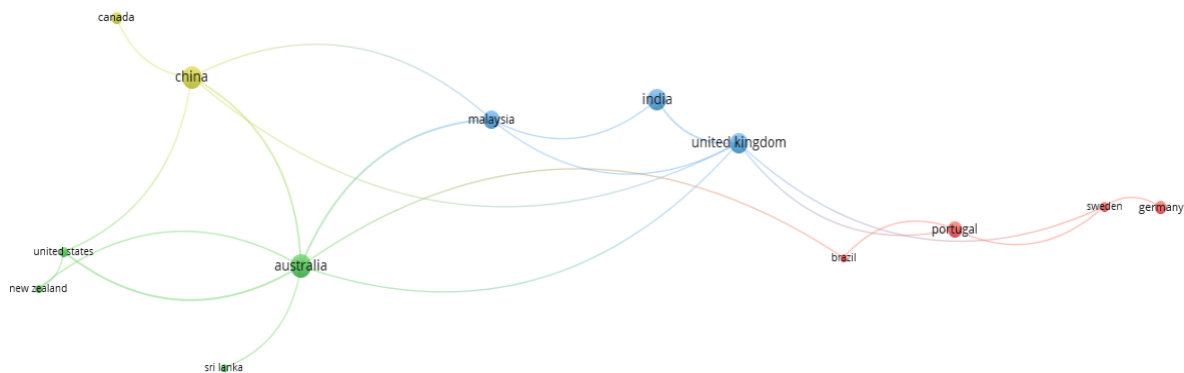

Figure 3: A Network of Cooperation Between Countries.

3.3 Analysis of collaborative networks of authors

Illustrated in Figure 4, the authors' collaboration network provides insight into those who have engaged in research concerning this specific topic. A comprehensive understanding of scientific collaborations among researchers within a given domain holds immense significance for enhancing accessibility to funding opportunities, expertise, and overall productivity expansion. The scientific collaboration between researchers can always be determined using co-authorship networks (Opoku et al., 2023). According to the findings, there is very minimum scientific collaboration between researchers in procurement and management of building services. Out of 102 papers, only one collaboration link can be seen with Thio-Ac A.; Domingo E.J.; Reyes R.M.; Arago N.; Jorda R., Jr.; Velasco J. and Joseph Jerome J.J.; Saxena D.; Sonwaney V.; Foropon C. -Ac A . Hosseini et al. (2018) highlighted that a lack of collaboration among researchers results in lower research productivity across specific domains. This observation derives the scarcity of research in this area and raises the necessity for further research.

Figure 4: Analysis of Collaborative Networks of Authors.

3.4 Collaboration network of institutions

Effective collaboration among organisations is an asset in research in formulating policies and establishing partnerships (Opoku et al., 2023). Institutional collaborations become a critical factor when trying to apply systematic and digital solutions to the construction industry. In creating the network of collaborations between the institutions, "co-authorship" was selected for the analysis type, whilst "organisations" was chosen for the unit of analysis. In terms of the counting method, "fractional counting" was also chosen instead of full counting. The "minimum number of documents of an organisation" as well as the "minimum number of citations of an organisation" were set to 1, to aid in achieving an optimal, legible, and reproducible network. The resultant network comprised 7 out of 203 organisations that met the threshold. According to Figure 5, there is a good collaboration of research related to procurement and management of building services between Australian, Thailand and United Kingdom research institutes. However, there is a further need to build stronger institutional networks to foster higher standards of scholarships and deliberation on the adoption of blockchain technology in the procurement and management of building services.

Figure 5: Collaborative Network Among Institutions.

3.5 Trending technologies for procurement and management in general

Shrivastava and Mahajan (2016) mentioned, that analysing keywords allows for determining the main research interests in any field. A network comprising keywords provides a comprehensive picture of a knowledge domain, allowing insight into existing research interests, and their intellectual connections (Van Eck and Waltman, 2014). Thus, a keyword co-occurrence network was produced using VOSviewer 1.6.19 software. The co-occurrence network of keywords consists of nodes (representing the keywords) and edges (representing relations among sets of keywords). "Author keyword" was chosen as the unit of analysis as an alternative to all keywords inputs of the software to enhance the clarity of the keyword image during the generation of the keyword co-occurance network.

It is worth mentioning that it has the limitation of being heavily dependent on the author's level of knowledge and experience in determining the relevant keywords (Darko et al., 2020). As an attempt to address this limitation, the study experimented with all keywords rather than author keywords and resulted in an unreadable and unrealistic network of keywords due to the sheer volume of keywords. Further, fractional counting was used in the counting method. Fractional counting represents a counting method that provides convenience for reducing the impact of publications with many authors, in co-authorship analysis (Eck and Waltman, 2019). Regarding the "minimum number of occurrences" for a keyword to be included in the network, a value of 2 was selected. This resulted in 310 keywords being extracted from the dataset and only 49 met the threshold. This criterion was achieved after several experiments to produce an optimal, reproducible, and legible network. Other previous studies (Wuni et al., 2019, Opoku et al., 2023, Darko et al., 2020) have utilised the same criterion in developing the networks. Other criterion selections in this research were based on this same approach. The resultant network consisted of 49 nodes and 206 relations, as illustrated in Figure 6.
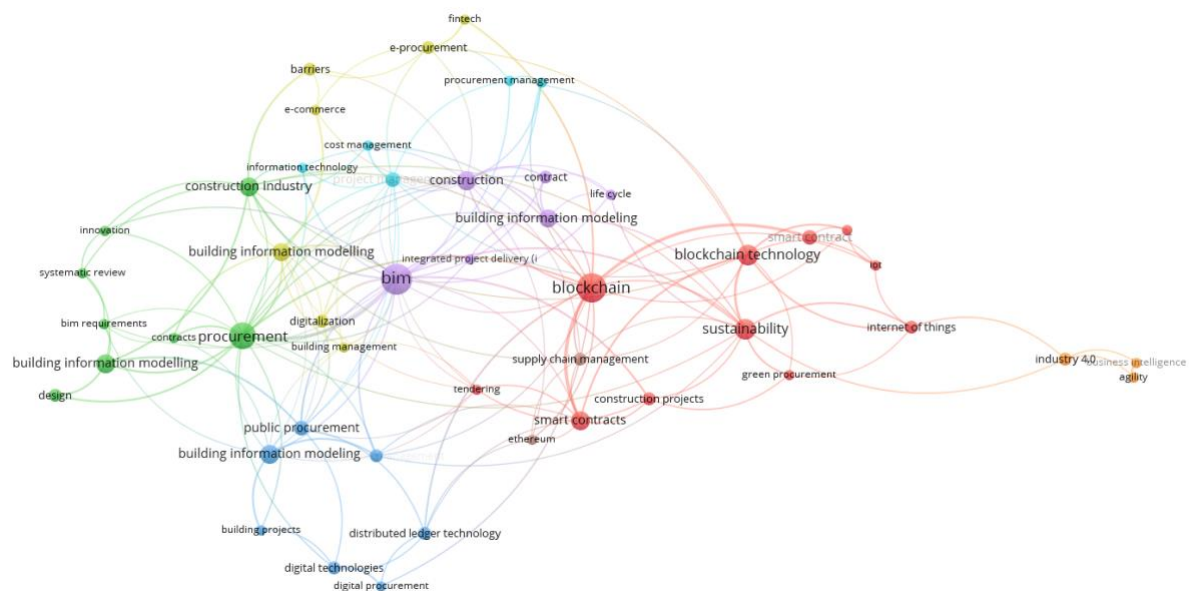
Figure 6: Keywords Co-occurrence Network in Procurement and Management.

Further, identical terms, for example, bim, building information modelling, building information modeling and blockchain, blockchain technology, smart contracts and construction, construction industry were merged as BIM, Blockchain and Construction industry respectively. In addition, the study omitted generic keywords such as survey and case study. This is illustrated in Table 1.

Table 1: Most Active Keywords in Procurement and Management.

Keyword	Occurrence	Total Link Strength
bim	18	16
building information modelling	6	5
building information modeling	7	4
building information modeling (bim)	6	4
building information modelling (bim)	7	5
Total	44	34
blockchain	16	15
smart contracts	7	7
smart contract	4	3
blockchain technology	8	6
distributed ledger technology	3	3
Total	38	34
procurement	13	13
public procurement	4	4
e-procurement	3	2
contract	3	3
Total	23	22
project management	7	7
sustainability	8	8
construction	7	7
construction industry	7	6
construction projects	3	3
supply chain management	3	3
Total	35	34
digital technologies	3	2
digitalisation	3	3
industry 4.0	3	1
internet of things	3	3
barriers of digitalisation	3	2
Total	15	11

According to Figure 6 and Table 1, Building Information Modelling (BIM) is the most popular tool used in procurement and management (With 44 Co-occurrence and 34 Total link strength). The adoption of Building Information Modelling (BIM) has initiated a trend towards enhanced coordination and integration of data from diverse fields (Celik et al., 2023, Hewavitharana et al., 2023). Data and information come in various formats and are generated and maintained by different groups of users and communities (Hewavitharana et al., 2021). Coordinating this data across different disciplines such as architecture, and structural engineering for project tasks can be challenging, as there are difficulties in interoperating and integrating diverse and distributed resources. BIM offers a centralised, consistent, and reliable source of information, optimum collaboration and knowledge

exchange across all disciplines (Krämer and Besenyői, 2018). However, it is unable to support continuous updates or tampering with digital records, including changing the date, time, or other metadata operations within the BIM model. This is because, BIM software is primarily built with the focus of managing and visualising information related to the building design, construction and management, which includes 3D models, 2D drawings, and non-graphical data (meta-data) of the building elements, such as material properties, energy consumption, etc (Jelodar et al., 2021, Hewavitharana and Perera, 2020). Although BIM tools allow users to make changes to project information, they may not include advanced security features or tamper-proofing mechanisms that are required to protect the integrity of digital records and guarantee the authenticity of the data.

Further, Web-based Enterprise Resource Planning (ERP) and web-enabled project management software applications are identified as "Integration and collaborative technologies" for procurement and management to ensure constant and unimpeded communication of project data among stakeholders (Ibem and Laryea, 2014, Hewavitharana and Perera, 2019). Koscheyev and Hakimov (2019) have suggested using online public procurement platforms (e-procurement platforms) for Russian government procurement practices. Additionally, Cloud-Based Procurement Software is used by companies to have lower upfront investment, decrease the overhead and real-time information sharing. Process Automation systems with AI-driven technologies such as machine learning and predictive analytics are another initiative involved with procurement and management in general (Jelodar et al., 2021).

However, recent publications have identified blockchain as an emerging technology for procurement and management, with 38 occurrences and a total link strength of 33. It is worth noting that no article has addressed the procurement and management of building services. Compared to other technologies, blockchain can track the changes made to the project information over time. This enables us to determine who made a change when it was made, and what the change was. Thus, blockchain has the potential to mitigate risks related to lack of information traceability, thus providing a higher authority to paper-based records, while ensuring integrity, security of transactions, and trust. The subsequent section will delve into an exploration of how blockchain can serve as a prospective solution for the challenges associated with the procurement and management of building services.

3.6 Issues in procurement and management of building services

In this section, procurement and management issues related to building services are presented. A total of 28 issues were identified by the literature review. Table 2 shows the summary of the issues identified.

Table 2: Issues Identified in Procurement and Management of Building Services.

Stage	Issues	References
Common Issues	Over-Involvement of Stakeholders (IS1)	(Chauhan et al., 2022, Smart Hospitals Project and Pan American Health Organization, 2020)
	Lack of Trust (IS2)	
	Lack of Transparency (IS3)	(Akhil and Das, 2019, Yik et al., 2006, Ibem and Laryea, 2014)
	Delays in Approvals (IS4)	
Strategic Definition (P0)	Unclear Requirements of the Client (IS5)	(Yik et al., 2006, Singh et al., 2018)
	Sudden Changes in the Client's Requirements (IS6)	
	Miscommunication between Parties (IS7)	(Zou et al., 2007, Arslan et al., 2006)
Preparation and Briefing (P1)	Poor Decision-making based on Inaccurate Information (IS8)	

	Lack of Trust regarding Project Information (IS9)	(Chauhan et al., 2022, Aggarwal and Kumar, 2021b, Aggarwal and Kumar, 2021a)
Concept Design (P2)	Unclear Conceptual Designs (IS10)	
	Instantaneous Design Changes (IS11)	(Arslan et al., 2006)
Spatial Coordination (P3)	Inconsistencies in Documents (IS12)	
	Interoperability of Design Software (IS13)	(Scott et al., 2021)
Technical Design (P4)	Noncompliance with Building Regulations (IS14)	
	Clashes between Designs and Specifications (IS15)	(Agrawal et al., 2022)
	Low Quotation-to-Order Ratio (IS16)	
	Long and Complicated Tendering Processes (IS17)	(Ibem and Laryea, 2014, Zhao et al., 2016, Scott et al., 2021, Chauhan et al., 2022)
	Risks Associated with Insurance (IS18)	
	A Large Scale of Dark Purchasing (IS19)	(Chauhan et al., 2022)
	Conflicts in Contracts (IS20)	
	Supply Risks Associated with the Procurement Process (IS21)	(Arslan et al., 2006)
Manufacturing and Construction (P5)	Lack of Transparency in Manufacturing Procedure (IS22)	
	Not Comply with Quality Standards (IS23)	(Scott et al., 2021, Chauhan et al., 2022, Smart Hospitals Project and Pan American Health Organization, 2020)
	Issues related to Equipment Delivery (IS24)	
Handover (P6)	Issues in Service Provisions (IS25)	(Chauhan et al., 2022, Arslan et al., 2006)
Use (P7)	Lack of Proper Inspections (IS26)	
	Issues in Warranty Provisions (IS27)	(Safe Work NSW 2023)
	Lack of Adherence to Government Regulations (IS28)	

3.7 Blockchain technology and features

This section discusses the blockchain technology and its features. The features of blockchain are highlighted with italic words in front of the blockchain technique that has contributed to them.

The term "blockchain" denotes a decentralised database that generates, validates and documents encrypted digital asset transactions. As a data structure, a blockchain consists of an ordered list of blocks, where each block contains a list of transactions. Each block is "chained" back to the previous block, by containing a hash of the representation of the previous block (Proper History Records). The cryptographic hash function is a one-way function, meaning that it is practically impossible to derive the input from the hash value as an output (Sadeghi et al., 2022). Therefore, data stored in the blockchain transactions may not be deleted or altered without invalidating the chain of hashes (Immutability). In addition, every transaction is signed by the transaction sender using a private key. Such a digital signature is a valid proof of the authenticity of the data sent by the transaction sender (High Security). Trust in the blockchain is achieved from the interactions between nodes within the network (Integrity). The participants of the blockchain network rely on the blockchain software and the consensus protocol used by the peer-to-peer network

rather than relying on a trusted third party to facilitate transactions (Disintermediation) (Perera, 2021, Kim et al., 2020). Further, the concept of blockchain has been expanded to encompass distributed ledger systems that are used to validate and store any type of transaction (Distributed Sharability) (Lu et al., 2021a). Any node in the blockchain can request a transaction to be added, however, the transaction is only accepted if a majority of the nodes agree that it is a legitimate transaction (Verifiability) (Tyagi et al., 2021). This nature of blockchain allows the required level of transparency in any transaction (Accountability). The smart contract is another special technique associated with blockchain. They are computer programs that use if/then statements and are automatically executed when the specific conditions are met. Smart contracts offer immense transparency and have the potential to reduce the number of conflict points in operation (Disintermediation) (Shojaei, Xu et al., 2022). Figure 7 demonstrates the overview of the blockchain technology.
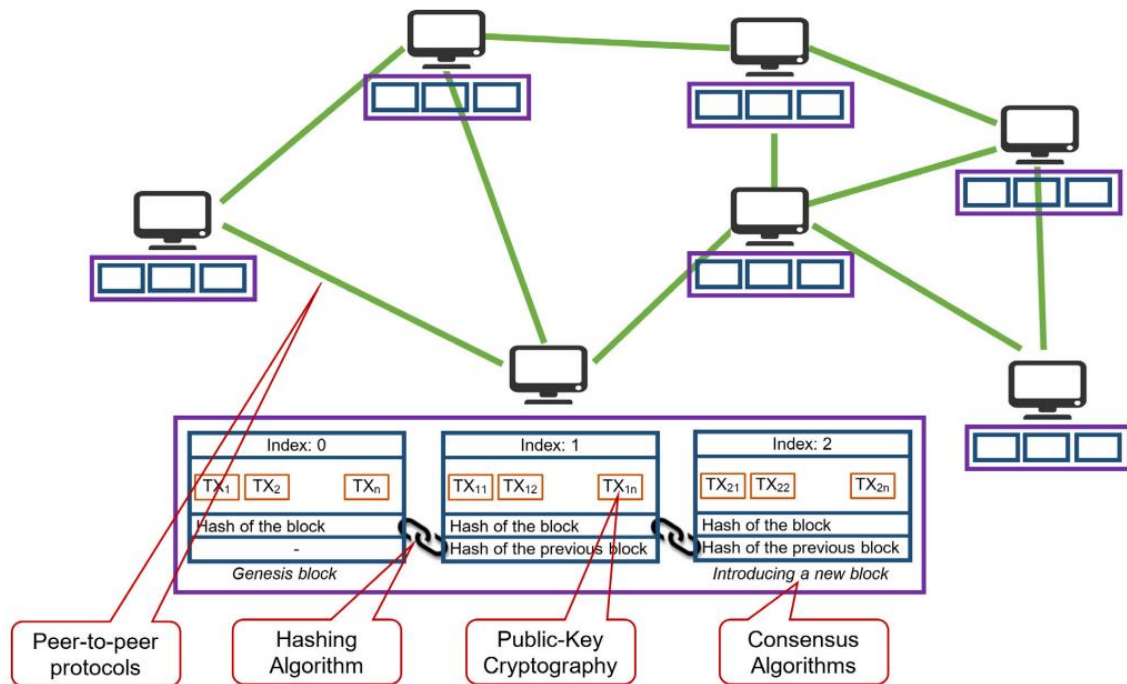

Figure 7: Blockchain Technology from (Perera et al., 2020).

3.8 The potential of blockchain in solving the issues

This section describes how the above-mentioned issues (Section 3.6) can be solved by the features of blockchain technology such as accountability, proper history record keeping, auditability, integrity, anonymity, disintermediation, verifiability, Distributed Shareability, immutability and high security.

Accountability: Building services systems involve multiple stakeholders throughout the design to dismantle and form various contracts and transactions. Most of these stakeholders are intermediaries who indirectly support the operations. Smart contracts deployed in blockchain can replace the intermediaries throughout the process by using automatically executable if/then conditions. Additionally, distributed ledger and P2P networks ensure all nodes can access the same data at any time while enhancing transparency and reducing disputes among the stakeholders (Scott et al., 2021, Perera et al., 2020).

Proper History Record Keeping: Building services systems have complicated tendering and quotation-to-order processes due to their complex design requirements (Hvam et al., 2006, Arslan et al., 2006). Those designs need various approvals at different stages and the tendering process gets delayed as there is no proper record-keeping mechanism in projects which is accessible to everybody. Blockchain's distributed ledger and real-time data-sharing

capabilities (P2P network) allow multiple parties involved in the quotation process to access a common data platform and reduce the reconciliation of data across disparate systems (Xinyi et al., 2018). Further, the consensus mechanism and the hashing algorithms ensure the recorded data are reliable and can not be altered (Albinson et al., 2023). This prevents continuous changes in the tendering and quotation process. Public key cryptography maintains the confidentiality of tender documents and quotations, and smart contracts support a selection of potential professionals without any bias.

Auditability: Blockchain provides high auditability for the information recorded in it (Angelis and Ribeiro da Silva, 2019). Through a P2P network and distributed ledger, all stakeholders have real-time access to transparent and immutable records, which reduces the potential for inaccurate or unreliable information(Kaushik et al., 2017). For instance, compliance with quality standards in building services systems can be reviewed by any authorised party from the manufacturing stage to the installation stage (Wu et al., 2022b, Singh et al., 2018). Further, all maintenance records of the building services can be retained in the blockchain ledger after the installation. These immutable and reliable records reduce the financial risk associated with the insurance and the supply chain.

Integrity: Integrity in the blockchain is crucial for resolving conflicts in contracts (Zou et al., 2007, Arslan et al., 2006). Smart contracts in blockchain are triggered once the conditions are met avoiding disputes over contract modifications or fraudulent alterations of all contract-related transactions (Aggarwal and Kumar, 2021a). The consensus mechanism further ensures that all parties agree on the validity of contract execution (Angelis and Ribeiro da Silva, 2019). As an example, contractual matters in building services such as decisions on design changes, warranty, service provision, quality compliances and insurance can be solved by smart contracts along with consensus mechanisms and hashing algorithms in the blockchain. Further, public key cryptography secures the confidentially of all contractual data by encrypting data with a recipient's public key which can only be decrypted by the corresponding private key (Khalfan et al., 2005).

Anonymity: A large scale of dark purchasing is a major issue in the procurement and management of building services (Tatum and Korman, 2000). Facilities such as public key cryptography, hashing algorithms and consensus mechanisms in blockchain can avoid large-scale dark purchases in building services by concealing the identities of participants in transactions (Anonymity), making it more challenging for malicious actors to engage in illicit activities (Li et al., 2019). Further, workflows and data exchanges in procurement and management of building services can be easily managed by introducing authorisation levels for relevant stakeholders.

Disintermediation: Blockchain facilitates disintermediation for multiple stakeholder involvement in building services by allowing direct peer-to-peer interactions and smart contracts that automate and enforce agreements, reducing the number of intermediaries (Liu et al., 2021). Further, a decentralised platform allows various outputs of design software to interact directly, overcoming the incompatibility and streamlining issues of design and construction processes (Nanayakkara et al., 2019a).

Verifiability: Blockchain provides proper verification through a combination of robust cryptographic techniques and consensus mechanisms (Nanayakkara et al., 2019b). Hashing algorithms produce unique hashes for each block of data, ensuring data integrity and preventing unauthorized alterations (Nanayakkara et al., 2021a). Consensus mechanisms ensure that all parties properly verify the transaction. Public key cryptography secures data with encrypting and decrypting mechanisms. Further, once this data is verified and added to the system it is immutable (Nawari and Ravindran, 2019). As an example, unclear client specifications in building services systems cannot be added to the blockchain without proper verification by other stakeholders. Therefore, a client cannot make sudden changes to the proposed and agreed designs without valid reasons.

Distributed Shareability: Distributed ledger and peer-to-peer networks in blockchain offer a transformative solution for distributed information sharing in building services (Ni et al., 2021). It eliminates intermediaries, and central authorities and connects all stakeholders to a one platform where data is real-time updating and transparent (Required transparent level) (Perera et al., 2021c). Therefore, multiple stakeholders in the procurement and management of building services can rely on a single trusted source of information reducing disputes, enhancing collaboration, and expediting decision-making.

Immutability: Immutable records in blockchain ensure that all transactions related to procurement and management of building services are permanently recorded and tamper-proof. This transparency builds trust among stakeholders (Qian and Papadonikolaki, 2020). Further, this facilitates the detection and resolution of non-compliance issues related to building practitioner regulations by offering a clear and indisputable audit trail (Perera et al., 2021a).

High Security: Hashing algorithms in blockchain ensures the integrity of transaction records, making it nearly impossible to tamper with dark purchase data without detection (Perera et al., 2020). Consensus mechanisms establish an environment where the majority of participants must validate transactions, preventing unauthorized or fraudulent entries in the ledger (Rajasekaran et al., 2022). Public key cryptography guarantees the secure identification of participants and encrypts sensitive information, making it exceptionally challenging for illicit actors to access or manipulate data (Rodrigo et al., 2018). This creates robust security for the procurement and management of building services (Shojaei, 2019).

Please refer to Table 3 for the summary of how blockchain technology and its features can solve the issues related to procurement and management of building services.

Table 3: Potential of Blockchian Addressing the Issues of Procurement and Management of Building Services.

Stage	Issues	Blockchain Feature	Blockchain Technology						
			P2P Network	Hashing Algorithm	Public Key	Consensus Mechanism	Smart Contract	Distributed Ledger	References
Common	Over-Involvement of Stakeholders (IS1) (Chauhan et al., 2022, Smart Hospitals Project and Pan American Health Organization, 2020)	Distributed Shareability	√					√	(Kim et al., 2020, Mahmudnia et al., 2022)
		Disintermediation	√			√	√	√	
		Integrity		√	√	√	√		(Abdelhamid and Hassan, 2019, Msawil et al., 2022)
		Immutability		√	√	√			
	Lack of Trust (IS2) (Akhil and Das, 2019, Yik et al., 2006, Ibem and Laryea, 2014)	Accountability	√				√	√	(Gaetani et al., 2017, Zheng et al., 2017)
		Distributed Shareability	√					√	

	Lack of Transparency (IS3)	Disintermediation	√			√	√	√	(Kaushik et al., 2017, Nanayakkara et al., 2021b)
		Verifiability		√	√	√	√		
		Distributed Shareability	√					√	(Scott et al., 2021, Perera et al., 2020)
Strategic Definition (P0)	(Yik et al., 2006, Singh et al., 2018)	Verifiability		√	√	√	√		
		Immutability		√	√	√			(Kim et al., 2020, Nanayakkara et al., 2021b)
	Delays in Approvals (IS4)	Verifiability		√	√	√	√		
		Immutability		√	√	√			(Aggarwal and Kumar, 2021a)
	(Zou et al., 2007, Arslan et al., 2006)	Distributed Shareability	√					√	
		Immutability		√	√	√			(Lu et al., 2021a, Zhao et al., 2023)
Preparation and Briefing (P1)		Verifiability		√	√	√	√		
		Distributed Shareability	√					√	(Li et al., 2019)

Phase	Issue	Characteristic							Reference
	Unclear Requirements of the Client (IS5)	Immutability		√	√	√			
	(Chauhan et al., 2022, Aggarwal and Kumar, 2021b, Aggarwal and Kumar, 2021a)	Verifiability		√	√	√	√		(Liu et al., 2023, Zheng et al., 2018)
Concept Design (P2)		Verifiability		√	√	√	√		
		Immutability		√	√	√			(Kim et al., 2020, Nawari and Ravindran, 2019, Zyskind and Nathan, 2015)
	Sudden Changes in the Client's Requirements (IS6) (Arslan et al., 2006)	Verifiability		√	√	√	√		
		Immutability		√	√	√			(Lo et al., 2017, Wu et al., 2022a)
Spatial Coordination (P3)		Verifiability		√	√	√	√		
	Miscommunication between Parties (IS7)(Scott et al., 2021)	Distributed Shareability	√					√	(Lu et al., 2021b, Wang et al., 2022)
		Distributed Shareability	√					√	
		Disintermediation	√			√	√	√	(Li et al., 2019, Nawari and Ravindran, 2019)

Technical Design (P4)	Issue	Attribute								Reference
Technical Design (P4)	Poor Decision-making Based on Inaccurate Information (IS8)(Agrawal et al., 2022)	Verifiability		√	√	√	√			
		Immutability		√	√	√				(Liu et al., 2021, Wang et al., 2018)
	Lack of Trust Regarding Project Information (IS9) (Ibem and Laryea, 2014, Zhao et al., 2016, Scott et al., 2021, Chauhan et al., 2022)	Verifiability		√	√	√	√			
		Immutability		√	√	√				(Liu et al., 2021, Wang et al., 2017)
	Unclear Conceptual Designs (IS10)	Proper history records		√	√	√				
		Audibility		√	√	√				(Lo et al., 2017, Nanayakkara et al., 2021a)
		Accountability	√					√	√	
	(Chauhan et al., 2022)	Disintermediation	√				√	√	√	(Lu et al., 2021a)
	Instantaneous Design Changes (IS11)	Accountability	√					√	√	
		High security		√	√					(Liu et al., 2023, Viriyasitavat et al., 2019)
		Anonymity		√	√					

Category	Description	Characteristic							References
	(Arslan et al., 2006)	Immutability		√	√	√			(Coyne and Onabolu, 2017, Teisserenc and Sepasgozar, 2021)
		Verifiability		√	√	√	√		
		Accountability	√				√	√	(Coyne and Onabolu, 2017, Figueiredo et al., 2022)
	Inconsistencies in Documents (IS12) (Scott et al., 2021, Chauhan et al., 2022, Smart Hospitals Project and Pan American Health Organization, 2020)	Distributed Shareability	√					√	
		Accountability	√				√	√	(Kaushik et al., 2017, Tasca and Tessone, 2019)
		Audibility		√	√	√			
Manufacturing and Construction (P5)		Audibility	√	√				√	(Fu et al., 2020, Shojaei, 2019)
	Interoperability of Design Software (IS13)(Chauhan et al., 2022, Arslan et al., 2006)	Verifiability		√	√	√	√		
		Immutability		√	√	√			(Das et al., 2022, Hamida et al., 2017)
		Distributed Shareability	√					√	

Phase	Issue	Property							Reference
	Noncompliance with Building Regulations (IS14)(Safe Work NSW 2023)	Verifiability		√	√	√	√		(Kaushik et al., 2017, Scott et al., 2021)
Handover (P6)		Verifiability		√	√	√	√		
		Immutability		√	√	√			(Dai et al., 2019, Ni et al., 2021)
Use (P7)	Clashes between Designs and Specifications (IS15) (Latiffi et al., 2013, Aggarwal and Kumar, 2021b, Aggarwal and Kumar, 2021a)	Audibility	√	√				√	
		Audibility	√	√				√	(Das et al., 2022, Nanayakkara et al., 2019b)
		Verifiability		√	√	√	√		

4. CONCLUSION AND RECOMMENDATIONS

This literature review has provided a comprehensive overview of the applicability of blockchain for systematic procurement and management of building services. The science mapping method was used to systematically and quantitatively analyse 102 publication-related bibliographic records retrieved from Scopus and the Web of Science databases. According to the findings of the bibliometric analysis, there is a very minimal collaboration of countries, organisations and authors regarding the publication in procurement and management of building services. Further, findings reveal that BIM is the major software used in procurement and management, however, advanced security features or tamper-proofing mechanisms that are required to protect the integrity of digital records and guarantee the authenticity of the data are not embedded with BIM. Additionally, 28 issues related to the procurement and management of building services are identified and solutions for them using blockchain technology are presented.

Over the past few years, researchers have been conducting research applying blockchain technology in construction. However, none of the research discusses the application of blockchain in building services. This paper presented the first comprehensive systematic study appraising the state-of-the-art research on blockchain in building services. For theory, the present study is unique in several ways: unlike prior review studies in the field, the results are reproducible and grounded in quantitative analysis of the literature, minimising subjective judgment; the study has covered almost all the research activities carried out related to procurement and management of building services thus, can use as a principle document for future research; the study open pathways for other researchers to apply blockchain technology in building services. In practical terms, this study can aid practitioners, policymakers and research and development bodies with a synthesized and readily available point of reference that captures the state-of-the-art research on blockchain in the procurement and management of building services.

This study encourages to application of blockchain technology in the procurement and management of building services as it is still struggling with security, trust, and coordination issues within these operations. The practical implementation of blockchain technology in the P&M of building services can be summarised as follows: Smart contracts can reduce the over-involvement of stakeholders in the P&M of building services by replacing intermediaries using if/then conditions and can reduce the disputes among stakeholders using well developed smart agreement. By utilising blockchain's distributed ledger and real-time data-sharing capabilities, multiple parties involved in the quotation process can access a shared data platform, reducing the need for data reconciliation across different systems. With a peer-to-peer network and distributed ledger, stakeholders have real-time access to transparent and immutable records, decreasing the likelihood of inaccurate or unreliable information. Public key cryptography, hashing algorithms, and consensus mechanisms in blockchain technology can prevent large-scale dark purchasing transactions in building services by concealing the participant identities. Further, unclear client specifications cannot be added to the blockchain without proper verification by other stakeholders, ensuring data integrity. The immutable nature of blockchain records guarantees that all transactions related to the P&M of building services are permanently recorded and resistant to tampering which fosters trust among stakeholders. Consensus mechanisms reinforce integrity by requiring the validation of transactions by a majority of participants, thus preventing unauthorised or fraudulent entries in the ledger. However, when applying blockchain technology stakeholders and their interaction is a significant concern where researcher has to pay more attention. Moreover, a thorough analysis is essential to identify realistic processes in the procurement and management of building services. Future research endeavours could investigate the stakeholder interaction and process associated with procurement and management of building services enabling the optimal integration of blockchain technology.

Currently, BIM software plays a major role in Building Services. However, BIM is unable to support continuous updates or tampering with digital records, including changing the date, time, or other metadata operations within the BIM model. This is because, BIM software is primarily built with the focus of managing and visualising information related to the building design, construction and management. Therefore, further research can be carried out to identify the ways BIM models can be incorporated with Blockchain technology to have seamless cooperation between designs and information.

Adopting blockchain technology in construction may face many challenges primarily due to the traditional practices of the industry. It will require embracement of changes and re-engineering of processes. Such changes include organizational, technological, mindset, nature of business competition and cultural changes. Therefore, construction organisations must make the working environment embrace blockchain technology. This can be carried out by making the workforce smart. Capacity-building programmes, technological training, cross-functional collaboration, and deep/lasting working cultural changes may make the working environment more

digital. Additionally, integrating blockchain with prevailing construction management systems and software will raise interoperability issues. Developing standardised protocols and APIs will facilitate integration with current tools and platforms. The initial investment of a blockchain solution will be significant for stakeholders and, thus will be reluctant to invest without a clear understanding of the potential return on investment. As a solution, pilot projects, case studies and cost-benefit analysis will support to understand the true benefit and justify the investment decisions.

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