Hewavitharana, S., Perera, S., Jin, X., Seneviratne, K. and Bamdad, K., 2023. An introduction to blockchain in building services: A literature review. In: Sandanayake, Y.G., Waidyasekara, K.G.A.S., Ramachandra, T. and Ranadewa, K.A.T.O. (eds). *Proceedings of the 11th World Construction Symposium*, 21-22 July 2023, Sri Lanka. [Online]. pp. 135-148. DOI: https://doi.org/10.31705/WCS.2023.12. Available from: https://ciobwcs.com/papers/

AN INTRODUCTION TO BLOCKCHAIN IN BUILDING SERVICES: A LITERATURE REVIEW

Sachindra Hewavitharana[1], Srinath Perera[2], Xiaohua Jin[3], Krisanthi Seneviratne[4] and Keivan Bamdad[5]

ABSTRACT

Mechanical, Electrical and Plumbing (MEP) systems often comprise a significant part of the construction project. These are complex systems with high stakeholder involvement, a lengthy lifecycle, and high financial cost. Due to this nature, MEP systems have complex procurement and management requirements which create uphill of challenges such as lack of transparency, instantaneous changes in designs, lack of trust, incompatibility of designs and specifications, lack of coordination, miscommunication, lack of security, traceability and confidentiality etc. This paper presents an analysis of how Blockchain technology can be used to address the issues arising from the procurement and management (P&M) of MEP systems. A literature review approach was used to identify issues in P&M of MEP systems that could benefit from the implementation of Blockchain technology. P&M phases of MEP systems is based on RIBA (2020). The literature review was carried out using articles in ScienceDirect that appeared in the context of MEP and Blockchain-related terms such as "Blockchain and MEP", and "Blockchain and building services practices". Forty papers were studied to gain insight into the issues, features of Blockchain technology and to explore how these features can provide possible solutions to the identified issues. In conclusion, this paper established that Blockchain technology can be used as a solution for the issues associated with each stage of the P&M of MEP systems.

Keywords: *Blockchain; Literature Review; Management; MEP Systems; Procurement.*

[1] Ph.D. researcher, Centre for Smart Modern Construction, Western Sydney University, Australia, sachindra.hewavitharana@westernsydney.edu.au
[2] Professor, Centre for Smart Modern Construction, Western Sydney University, Australia, srinath.perera@westernsydney.edu.au
[3] A/Professor, Centre for Smart Modern Construction, Western Sydney University, Australia, xiaohua.jin@westernsydney.edu.au
[4] Lecturer, Centre for Smart Modern Construction, Western Sydney University, Australia, k.seneviratne@westernsydney.edu.au
[5] Lecturer, Centre for Smart Modern Construction, Western Sydney University, Australia, k.bamdad@westernsydney.edu.au

1. INTRODUCTION

Mechanical, Electrical, and Plumbing (MEP) systems are essential for the functioning of a structure. These systems are responsible for the features that make a building habitable and comfortable, no matter the size or complexity of the structure. Not only the comfortableness but also life safety is provided by the MEP systems for the building occupants (Chauhan et al., 2022; Kumari et al., 2022).

MEP systems are taking up a larger share of construction projects (Zhao et al., 2016). These systems provide the necessary functions for a building to operate properly, however, they can come at a much higher cost than other building systems such as architectural and structural. They usually make up a large portion of the total construction costs (typically ranging from 15% to 60%) which is a major factor in the final overall project price (Chauhan et al., 2022). The expense of an MEP system can vary substantially, depending on the magnitude and intricacy of the project. The installation of the MEP systems can take up to a maximum of 50% of the entire duration of the project (De Almeida et al., 2009). Thus, it is paramount to the success of a construction project (Wang et al., 2017).

However, not like other resources, MEP systems typically have a complex procurement requirements and work with large number of specified material components which are sourced from a variety of suppliers and manufacturers. The traditional manual procurement and management processes which adopted for MEP systems are time-consuming, expensive, and tend to contain mistakes due to the human factor. Further, currently there is no unified systems even support all construction procurement processes and data exchanges (Fernando et al., 2019; Hewavitharana et al., 2021; Perera et al., 2021). For example, Building Information Modelling (BIM) enhances the transferring and managing of information by detecting clashes, 3D modelling, constructability analysis and cost estimation (Hewavitharana & Perera, 2020; Teo et al., 2022), but not supported to solve issues related to procurement in supply chains (Perera et al., 2021).

MEP engineers and other professionals face uphill challenges due to the lack of transparency, instantaneous changes in designs, lack of trust, incompatibility of designs and specifications, lack of coordination, miscommunication, lack of security, traceability and confidentiality (Hewavitharana et al., 2019; Rabb & Vesali, 2022; Xu et al., 2021). Because of these issues, construction organisations consider different ways to incorporate novel concepts and adopt novel strategies to enhance their operations (Turner et al., 2021; Zou et al., 2007). Perera et al. (2021) signify that construction procurement and management is an area wherein new technology adoption should be given particular attention. As mentioned above, MEP is one of the most paramount sectors in construction projects and technology adoption in procurement and management of MEP systems is further essential. With the Industry 4.0, there are number of technologies (e.g., BIM, IoT, AI, Cloud Computing, AR, Blockchain) which revolutionised the construction industry (Alaloul et al., 2020). However, when consider the issues in procurement and management of MEP systems and unique feature of Blockchain, it is established that Blockchain is the one best solution to address the identified issues.

2. METHODOLOGY

A literature review can be labelled as a well-established method for accumulating existing knowledge within a domain of interest (Mingxiao et al., 2017). As the methodology for this article, it is expected to apply literature review approach. To find the relevant articles for reviewing, various keywords were searched within ScienceDirect database. ScienceDirect is selected because it is one of the leading sources of scientific, technical and medical research. The publishing period was decided to lie between 2015-2023 to reduce the search scope. Different keywords such as "Blockchain in procurement of MEP", "Blockchain in management of MEP", "Blockchain in MEP projects", "Blockchain and MEP", "Blockchain and building services practices", "application of Blockchain" were used to find relevant articles. However, articles were identified relating to the targeted topic in specific. The topics were broadened, and the articles' abstracts were carefully read to check their relevance. After having a critical literature review of forty selected articles as shown in Figure 1, issues in the procurement and management of MEP systems were identified. Procurement and management of MEP systems is divided in to eight phases according to the RIBA Plan of Work (2020). Issues in each phases were identified separately. Then, the features of Blockchain were investigated. Subsequently, the features of the Blockchain mapped to solve the identified issues.

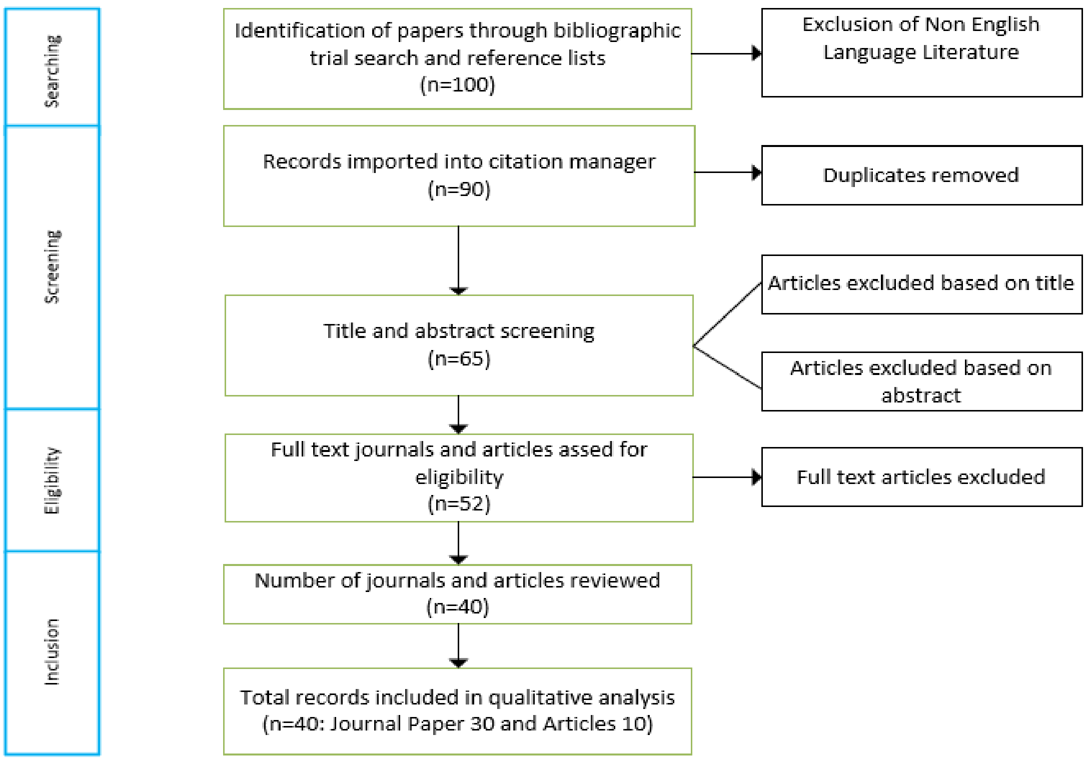

Figure 1: Derivation of referred Journal papers and Articles

3. DISCUSSION

3.1 PROCUREMENT AND MANAGEMENT OF MEP SYSTEMS

MEP systems have a complex procurement requirements and work with large number of specified material components which are sourced from a variety of suppliers and manufacturers (Xu et al., 2021). Planning of MEP procurement is much critical than normal construction materials. As outlined above, the cost and timeline associated with MEP systems are significant, creating a high risk to the construction project. To avoid the risks, MEP procurement is heavily based on MEP design and specifications. Additionally, special subcontractor (expert in MEP) is selected for MEP system installation through single or two-stage tender process (Mosley Jr & Bubshait, 2017). After the selection, MEP subcontractor can make special provisions for unknown levels of risk if the design is simple. Before finalising the designs, all stakeholders must collaborate each other to avoid clashes in each discipline. This is a back-to-back and time-consuming process (Teo et al., 2022). Therefore, it is established that MEP procurement is complicated and much riskier than usual procurement of construction materials. Further, it empathises the necessity of systematic procurement method which will lead to greater level of certainty, avoiding requirement changes and re-work.

In this study, it is expected to consider all the operation of MEP systems from planning to maintenance and disposal (procurement and management). Therefore, in here, “procurement” denotes procedures from planning to installation of MEP systems as per the above-mentioned definition (Perera et al., 2021). In other terms, “procurement” states the processes related to pre-installation of the MEP systems. “management” implies the maintenance and disposal of MEP systems. Simply, it illustrates the processes associated with the post-installation of MEP systems.

Understanding the processes of whole procurement and management of MEP systems is difficult. Thus, it is divided into eight stages based on RIBA Plan of Work (2020). They are Strategic Definition, Preparation and Briefing, Concept Design, Spatial Coordination, Technical Design, Manufacturing and Construction, Handover and Use. RIBA Plan of work (2020) is considered as the most prominent framework which is used to organise any construction project (Celik et al., 2023). It evolved through its history to reflect the increasing complexity of projects, to incorporate increasing and changing regulatory requirements and to reflect the demands of industry and government reports criticising the industry. Although RIBA Plan of Work (2020) refers to the stages of construction project it can also utilised to MEP works, as MEP works are embedded in the scope of work of a construction project. Further, the terminologies used in the RIBA plan of works (2020) can be easily incorporated to the MEP Plan of Woks. After establishing RIBA Plan of Work (2020) as the basis of deriving stages, the stages of RIBA are mapped with MEP services. Core activities which are implemented in each stage are summarised in Table 1. The stages are denoted from P0-P7.

Table 1: Phases for the study

Phase No	RIBA Plan of Work	Core activity related to P&M of MEP
P0	Strategic Definition	Identify client’s requirement (MEP)
P1	Preparation and Briefing	Feasibility study of installing MEP (E.g Energy Consumption)
P2	Concept Design	Concept designs regarding MEP systems
P3	Spatial Coordination	Checking MEP spatial requirement and clash detection
P4	Technical Design	Technical design, Tendering and documentation for MEP installer selection
P5	Manufacturing and Construction	Manufacturing/Customising/Assembling MEP systems and Installation
P6	Handover	Handover the MEP system to the Client
P7	Use	Maintenance and Disposal of MEP systems

Having discussed the phases of procurement and management of MEP systems, following section describes the issues raised in each stage.

3.2 ISSUES IN PROCUREMENT AND MANAGEMENT OF MEP SYSTEMS

Having done a critical literature review on issues of P&M of MEP system, Table 2 is developed as a summary.

Table 2: Issues in MEP Procurement and Management

Stage	Issues	References
General Issues	Multiple stakeholders are involved in the MEP coordination process and can lead to numerous clashes (I1)	(Chauhan et al., 2022; UKAID, 2013)
	Difficulty in establishing trust, exchanging data, and managing the workflow (I2)	(Akhil & Das, 2019; Ibem & Laryea, 2014; Yik et al., 2006)
	Lack of transparency (I3)	(Singh et al., 2018; Yik et al., 2006)
	Delays in approvals (I4)	(Arslan et al., 2006; Zou et al., 2007)
Strategic Definition (P0)	Unclear requirements of the client (I5)	(Aggarwal & Kumar, 2021a, 2021b; Chauhan et al., 2022)
	Sudden changes in the client's requirements (I6)	(Arslan et al., 2006)
	Miscommunication between parties and lack of trust (I7)	(Scott et al., 2021)
Preparation and Briefing (P1)	Poor decision making based on inaccurate information (I8)	(Agrawal et al., 2022)
	Lack of trust regarding project information (I9)	(Chauhan et al., 2022; Ibem & Laryea, 2014; Scott et al., 2021; Zhao et al., 2016).
Concept Design (P2)	Unclear conceptual designs (I10)	(Chauhan et al., 2022)
	Instantaneous feedback about the design decisions (I11)	(Arslan et al., 2006)
Spatial Coordination (P3)	Clashes related to missing information, poorly communicated information, inconsistencies between documentation (I12)	(Chauhan et al., 2022; Scott et al., 2021; UKAID, 2013)
	Incompatibility among design software (I13)	(Arslan et al.; Chauhan et al., 2022)
	Lack of trust between parties (I14)	(Chauhan et al., 2022)
	Miscommunication between parties and lack of transparency (I15)	(Scott et al., 2021)
Technical Design (P4)	Noncompliance with building practitioner regulations (I16)	(Work Safe, 2022)
	Detection of potential clashes between design and specifications (I17)	(Aggarwal & Kumar, 2021a, 2021b; Latiffi et al., 2013)
	Low quotation to order ratio (I18)	(Hvam et al., 2006)
	Long and complicated tendering processes (I119)	(Hvam et al., 2006)
	Risks associated with insurances (I20)	(Zou et al., 2007)

Stage	Issues	References
	Large scale of dark purchasing (I21)	(Tatum & Korman, 2000)
	Conflicts in Contracts (I22)	(Zou et al., 2007)
	Inaccurate and non-reliable information (I23)	(Hvam et al., 2006)
	Supply risks associated with procurement process (I24)	(Nanayakkara et al., 2019)
Manufacturing and Construction (P5)	Lack of transparency in manufacturing procedure (I25)	(Singh et al., 2018)
	Not comply with quality standards (I26)	(Singh et al., 2018; Wu et al., 2022)
	Conflicts in compliance (I27)	(Wan & Kumaraswamy, 2012)
	Issues related to equipment delivery (I28)	(Zou et al., 2007)
Handover (P6)	Issues in service provisions (I29)	(Howkins, 2017; Korman et al., 2003; Work Safe, 2022)
Use (P7)	Lack of proper inspections (I30)	(Howkins, 2017)
	Issues in Warranty Provisions (I31)	(Howkins, 2017)
	Lack of adhering to the government regulations (I32)	(Work Safe, 2022)
	Difficult in decision making due to lack of information (I33)	(KONE Cooperation, 2019)

Having identified the issues following sections describe how Blockchain technology can positively impact to the procurement and management of MEP systems.

3.3 BLOCKCHAIN TECHNOLOGY

The term "Blockchain" refers to a decentralised database which creates, validates and records encrypted transactions of digital assets in an incorruptible way. As a data structure, a Blockchain is 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. The *hash value* is generated by a cryptographic hash function. The 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. 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 (Wu et al., 2019). Trust in the Blockchain is achieved from the interactions between nodes within the network. The participants of *Blockchain network* rely on the Blockchain software and the consensus protocol used by the peer-to-peer network rather than relying on trusted third-party to facilitate transactions (Kim et al., 2020; Perera, 2021). Further, the concept of Blockchain has been expanded to encompass *distributed ledger systems* that are used to validate and store any type of transaction (Lu et al., 2021). *Smart contracts* can be thought of as computer programs that use if/then statements to divide a project's work into smaller, measurable packages, and automate the process of compliance and payment (Xu et al., 2022). Each work package or milestone is defined by specific conditions, and when these conditions are met, the predetermined compensation is triggered automatically. This approach provides a new type of work breakdown structure, which enables all stakeholders to better comprehend their obligations and requirements.

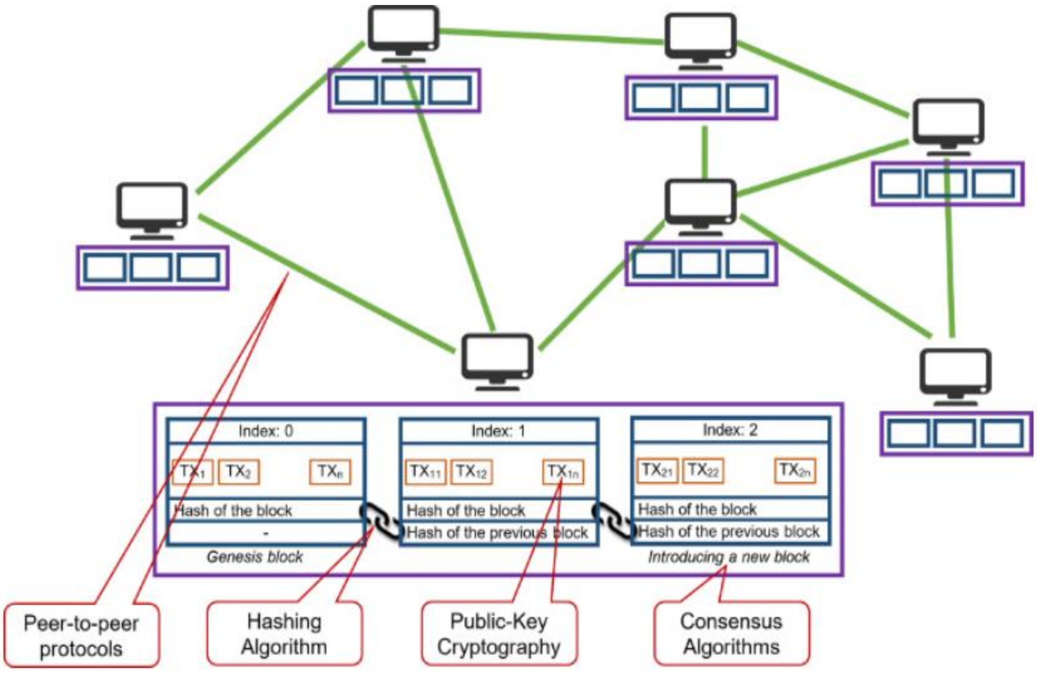

Figure 2: Peer-to-Peer Blockchain Architecture
Source: (Perera et al., 2021)

3.4 POTENTIAL OF BLOCKCHAIN TO SOLVE THE ISSUES IDENTIFIED IN PROCUREMENT AND MANAGEMENT OF MEP SYSTEMS

Following section describes how Blockchain technology can positively impact to the procurement and management of MEP systems.

- In the design phases, Blockchain enables to cooperate with other digital tools like BIM. As an example, Blockchain technology can store a hash of the BIM model, which can be used by a lookup service to compare the hash of a downloaded model with the hash stored on the chain. The application then provides the user with a verification receipt that confirms the model's validity (Scott et al., 2021). On another note, a case study by Mason (2019) has proven that how logging geometry and volume in BIM models can be translated into computable code for smart contracts.

- Smart contracts in Blockchain can be applied to contract agreements between clients and construction parties, as well as between clients and their project consultants such as designers, cost engineers, and project managers (Das et al., 2019). This will help addressing issues related to non-payment or late-payment, which are often faced in current construction contracts, by utilising a trust-in-machine concept in Smart Contract. As a result, the nature of legal contracts in construction will likely undergo a significant change, with prevention taking precedence over litigation (San et al., 2019).

- Sometimes MEP manufacturer and customising companies try to keep sovereignty in the market. In Australia, most of the MEP systems are imported from other countries like China, USA, Germany, Southeast Asia etc. For example, very few lift manufacturing companies can be seen in Australia who manufactures lifts. This results in quality issues in the MEP system (Mostafa et al., 2018). Blockchain based monitoring system supports to track the MEP system from manufacturing stage to installation stage ensuring that MEP systems are up to the required standards (Agrawal et al., 2022; Angrish et al., 2018).

- An automated, Blockchain-enabled system can help monitor maintenance procedures for the building. This system can easily and accurately manage maintenance requests, procurement processes, product delivery, payments, and more, thanks to the use of smart contracts (Xu et al., 2021). Its transparency also ensures that everyone involved from the occupant to other parties is kept up to date on the status of a maintenance request, from the beginning of the process to the completion of the work. Also, it enables maintenance managers to recognise who supplied and installed any building component at what cost at any given time (Li et al., 2019; Zakhary et al., 2019).
- Integration of Blockchain and Building Maintenance System (BMS) technology allows for the creation of a Decentralised Autonomous Organisation (DAO) to manage the lifecycle of a structure. This DAO is powered by multiple smart contracts, which can be used to automate the placement of maintenance work orders and the release of payments upon verification that the work is complete. The DAO can handle every aspect of a building's lifecycle, from design and construction to operation, maintenance and demolition, with the smart contracts working together to ensure that these processes are carried out in a cohesive and autonomous manner (Perera et al., 2020; Shojaei, 2019).
- A large number of stakeholders involved in the process of procurement and management of MEP systems lead to coordination issues and conflicts among parties. The use of Blockchain has the potential to revolutionise the way contracts and transactions are handled. It could reduce the costs associated with these activities while improving their security. Furthermore, it could lead to efficient coordination among many stakeholders involved in the process of procuring and managing MEP systems by creating new business models (Kim et al., 2020; Xu et al., 2022).
- Utilising product modelling and IT-based product configuration systems which supported by Blockchain allows for greater optimisation of quotation and engineering processes. This leads to a decrease in the costs associated with making a quotation, as well as improved efficiency in other areas, such as increased knowledge sharing, higher quality of quotations, and shortened lead-times (Akhil & Das, 2019). Additionally, Blockchain based product configuration systems can be used to support decision making and provide clarity regarding possible alternatives when configuring a new product (Hvam et al., 2006).
- Blockchain can be used as an immutable distributed ledger where transactions are timestamped into a block, which enables MEP asset tracking, ownership transfer certification and maintains accurate, immutable history records (D. Perera et al., 2021). Also, it ensures that project information is confidentially managed through the Blockchain. As an example, by using a Blockchain system that incorporates smart contracts, all parties involved can easily be notified of MEP drawing

updates (Nakamoto, 2008). This system would allow for the most current information to be readily available and would eliminate potential issues that can arise such as miscommunication of which version of the drawing is the latest, who issued it, and whether it was included with other drawings such as architectural, structural, and services (Perera et al., 2020).

- The use of digital tools enables real-time communication, coordination, collaboration, and sharing of project information and data between participants in project activities. However, the interoperability or incompatibility of different systems and software packages has been recognised as a persistent challenge. Blockchain promotes real-time communication and cooperation across the participants rather than promoting individual execution of computer software (Ibem & Laryea, 2014). Things can quickly go wrong when MEP systems are designed in isolation, rather than in a coordinated manner. That is why it is important to keep your whole team updated on how and where each system is being installed (Hewavitharana et al., 2019).
- Blockchain and intelligent contracts (iContracts) will eliminate the inherent issues in traditional contracts (McNamara & Sepasgozar, 2021). MEP asset management on a Blockchain network helps to solve the problems of dispute resolution and improves the time it takes to solve discrepancies in data. The consensus-based nature of the technology means that updates cannot occur to asset records without agreement from all relevant parties (Teisserenc & Sepasgozar, 2021).
- The core of MEP asset management entails the procedures of registering and transferring possession of an asset as per the provisions of a relevant agreement (Xu et al., 2022). This includes keeping a record of the assets belonging to a particular individual or entity, having a third party manage and administer payments on behalf of the parties involved in a transaction, and performing an atomic exchange of assets based on an amount that has been mutually agreed upon. An asset registry is responsible for maintaining a list of assets that are owned by a certain party. Asset swap is the optimal exchange of assets based on the amount that has been settled by the parties. Blockchain can act as a third party and release the payments when all the obligations of the agreement are fulfilled (Lu et al.; San et al., 2019).
- Blockchain technology offers transparency and trust in the MEP industry, allowing all parties involved to view a chronological record of both monetary and non-monetary transactions (e.g., drawings, property transfer). This visibility is shared among all participants in the transaction, regardless of whether it is financial or informational (Zakhary et al., 2019). The decentralised nature of Blockchain also ensures that all users have the same information, and that this data cannot be altered or deleted. Both the sender and receiver, therefore, have access to more information than is available elsewhere. This traceable and immutable record creates a sense of transparency for users, making them more likely to enter into smart contracts with one another, trusting the automated system rather than relying on an established trust relationship (Kim et al., 2020; San et al., 2019).

4. CONCLUSIONS AND THE WAY FORWARD

MEP systems are frequently a major element of building projects that involve a great deal of stakeholders, have a lengthy lifecycle, and require a great deal of financial expenditure. As a result of their complexity, MEP systems can be subjected to a variety of issues throughout the design to disposal process. Through a critical literature review, this paper examined how Blockchain technology can be leveraged to tackle these difficulties associated with procuring and managing MEP systems. To make it easier to understand, the procurement and management of MEP systems were divided into eight stages based on RIBA Plan of Work (2020). Major issues which identified are high involvement of third parties, poor coordination and clash detection, delay in approvals, lack of transparency, conflicts in contracts, lack of information sharing, conflicts in compliance, warranty leakages, etc. Blockchain was suggested as a solution for solving these issues because of its features such as peer-to-peer network, private key, distributed ledger, hash function and smart contracts. Blockchain could provide minimum third-party involvement, high transparency in contracts, strong verification systems, the immutability of data and auditability of data for the procurement and management of MEP systems.

Very limited studies have focused on finding solutions for the issues in the procurement and management of MEP systems. This paper presents a clear overview of how Blockchain can facilitate MEP procurement and management to develop collaboration among parties, reduce third-party involvement, trust issues, and clashes in contracts, and improve transparency in contracts in an effective manner.

Further investigations should be carried out to identify the stakeholder involvement and process which are related to MEP systems to explore the exact place where Blockchain should be embedded. As a concluding remark, the research outcomes demonstrate that Blockchain and smart contract-powered ICT solutions can significantly contribute to mitigate the issues related to the procurement and management of MEP systems.

5. ACKNOWLEDGEMENTS

The authors would like to acknowledge the support by the Centre for Smart Modern Construction of Western Sydney University, Australia and facilitators of the Centre.

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