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Exploring the Potential of Blockchain Technology in the Construction Industry: Applications and Implications

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ABSTRACT
Blockchain was presented as the underlying technology for digital currencies between untrustworthy parties. Today, its transformative potential is constantly compared to that of the Web, and practitioners and researchers from all domains are investigating how to use blockchain technology to deal with long-standing issues related to data integrity, transparency, and trust. Many studies and case study findings suggest that many industries are already investigating the numerous benefits of blockchain technology. An examination of how other industries use blockchain could aid in understanding how to fix similar problems in the construction industry. This paper examines the feasibility of using blockchain in the construction sector. According to the study results, block chain and its abilities are developed enough then to endorse many use cases in the construction sector, and the industry's resistance to new technologies being adopted appears to be the only barrier. Building information modeling and supply chain management (SCM) are two significant areas where blockchain technology might have a larger & immediate effect.

Keywords: *Engineering Management, Construction Management, Blockchain Technology, TQM, SCM, BIM.*

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I. INTRODUCTION

Blockchain technology was first introduced in 2008 with the emergence of cryptocurrency and Bitcoin(Nakamoto, 2008). Initially, it was primarily seen as a way to generate new cryptos and facilitate confidential transactions among untrustworthy participants across geographical boundaries. However, as industry professionals began to recognize the significant benefits of blockchain, new use cases emerged (Juszczyk & Shahzad, 2022).

The key properties of blockchain technology, such as immutability, continuity, transparency, and disintermediation, make it a valuable tool for various applications(Baiod, Light, & Mahanti, 2021). Immutability means that data stored on the blockchain cannot be altered or removed, while continuity ensures that the data remains accessible and unchanged over time(Berryhill, Bourgery, & Hanson, 2018). Transparency allows all members of the network to have access to the same information, while disintermediation eliminates the need for intermediaries, increasing efficiency and reducing the potential for errors or fraud (Hussain et al., 2022).

In contrast to traditional software systems, which are centralized and controlled by a single entity, blockchain technology is decentralized, making it more resistant to tampering and hacking(Xie et al., 2020). This decentralized nature also increases trust and transparency, as the data is not controlled by a single entity (J. Y. Lee, 2019).

Blockchain technology has the potential to transform a wide range of applications and services, including elections, electric grids, logistics providers, facilities management, and Agri-insurance(W. Chen, Xu, Shi, Zhao, & Zhao, 2018). It also has the potential to address many pressing issues in the construction industry, such as a lack of trust between stakeholders(W. Chen et al., 2018), supply chain continuity, payment delays and fraud, and a high number of administrative tasks that are prone to human error(Litke, Anagnostopoulos, & Varvarigou, 2019) .

II. METHODOLOGY

Blockchain technology has been around for a decade, but it is still a rapidly evolving field, with cryptocurrency being the most well-known application (Nakamoto, 2008). Understanding blockchain can be challenging as it involves various disciplines such as cryptography, mathematics, computer science, finance, economics, and politics (Buterin, 2014). While there are a few case studies and applications of blockchain in various industries, including construction(Tezel, Papadonikolaki, Yitmen, & Hilletofth, 2020), the limited number of experts in the field makes it difficult to gather data through methods such as interviews or questionnaires. Moreover, the general lack of understanding about blockchain among the general public means that primary data collected through surveys and questionnaires may not be reliable at this time. To collect qualitative data for this study, a four-step process was implemented, which involved reviewing a variety of secondary sources, such as case studies from other sectors (Step 1). The steps included:

Undertaking an extensive literature review on blockchain technology using various sources, including journal and conference papers, textbooks, technical whitepapers, and reputable online sources (Step 1).

Examining literature and internet sources to determine how blockchain is being utilized in different industries, with a focus on case studies and industrial applications in other industries that utilize blockchain technology (Step 2).

Carefully reviewing published expert reviews to identify common problems in the construction industry (Step 3).

Mapping out solutions from other industries that utilize blockchain technology to common problems in the construction industry and identifying potential applications of blockchain that could help address these issues (Step 4). These steps were selected in order to gather a wide range of information on the use of blockchain technology in various industries and to consider how it may be applied to address problems in the construction industry.

STUDY SCOPE

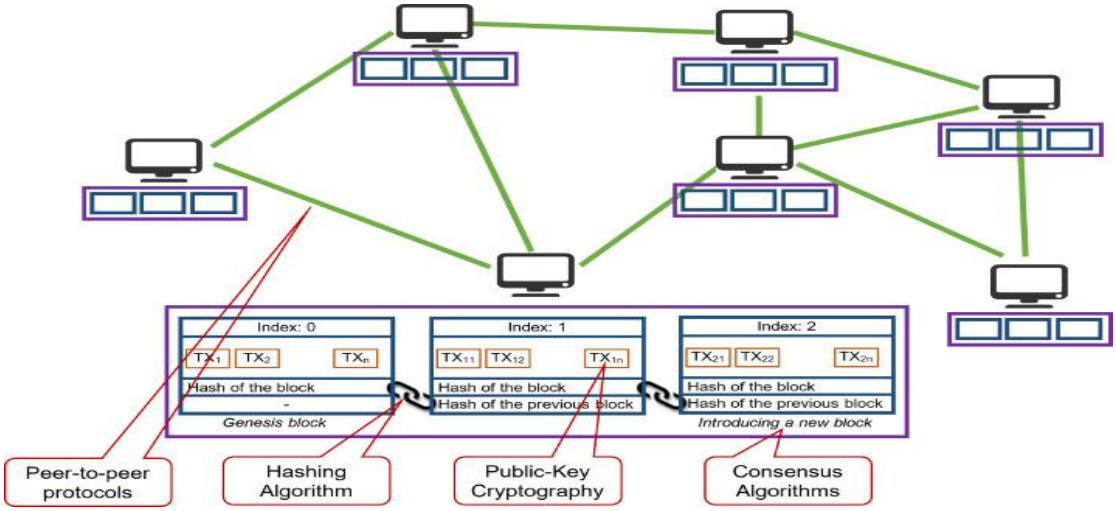
The focus of this study is on examining the potential use of blockchain technology in the construction industry, rather than the application of cryptocurrencies in the construction sector. The main scope of the research is to investigate how blockchain can be utilized to address common problems in the construction industry, drawing on lessons from the implementation of blockchain solutions in other industries. The research aims to provide insight into how blockchain technology can be applied to solve challenges faced in the construction industry.

BLOCKCHAIN

Blockchain technology was first introduced in 2008 as a way to securely and transparently record digital transactions(Zwitter & Boisse-Despiaux, 2018). It was initially developed as part of the cryptocurrency Bitcoin, but has since evolved to have a wide range of applications beyond just cryptocurrency (Abramova & Böhme, 2016). At its core, a blockchain is a decentralized and distributed digital ledger that allows for the secure and transparent record-keeping of transactions (Wüst & Gervais, 2018). It utilizes cryptography to ensure the integrity and immutability of the records, making it a secure and reliable platform for various applications (Berdik, Otoum, Schmidt, Porter, & Jararweh, 2021).

One of the key features of blockchain technology is its decentralized nature, which allows for peer-to-peer transactions without the need for a central authority(Shahidehpour, Yan, Shikhar, Bahramirad, & Paaso, 2020). This can increase transparency and trust in the system, as all transactions are recorded on a public ledger that can be accessed by anyone(Niranjanamurthy, Nithya, & Jagannatha, 2019). In addition to its use in cryptocurrency, blockchain has the potential to transform various industries by enabling secure and efficient transfer of value, information, and assets (Bonsón & Bednárová, 2019). Some examples of current and potential future uses of blockchain include supply chain management, identity verification, voting systems, and real estate transactions (Abeyratne & Monfared, 2016; Cole, Stevenson, & Aitken, 2019).

.Figure (1): Technologies and concepts behind the blockchain network(S Perera, Nanayakkara, & Weerasuriya, 2021)



Blockchain is a decentralized, distributed database that enables the secure storage and management of data. It is structured as a network of computers, called nodes, which store and manage data by holding a copy of the entire database(Muzammal, Qu, & Nasrulin, 2019). This decentralized structure helps to ensure the security and integrity of the data, as it is not controlled by a single entity and any changes to the data must be agreed upon by multiple nodes(Hammi, Hammi, Bellot, & Serhrouchni, 2018).

(Fang et al., 2020) mentioned that the cryptographic techniques, such as hashing and digital signatures, are used to secure data and ensure its authenticity. Hashing involves the use of a mathematical function to convert data into a fixed-size string of characters, known as a hash. This hash can then be used to verify the authenticity of the data, as any changes to the data will result in a different hash. Digital signatures, on the other hand, utilize public key encryption to verify the identity of the sender and ensure that the data has not been tampered with.

Consensus protocols, such as proof-of-work and proof-of-stake, are used to ensure the integrity of the data by requiring multiple nodes to agree on any changes to the data. In a proof-of-work system, nodes must solve a complex mathematical problem in order to add new data to the blockchain. This process, known as mining, helps to prevent malicious actors from altering the data without the consensus of the network. In a proof-of-stake system, nodes are chosen to validate new transactions based on the amount of cryptocurrency they hold, rather than the computational power they have. This helps to ensure that the nodes with the most invested in the network have the greatest say in its governance.(Kaur, Chaturvedi, Sharma, & Kar, 2021; Nguyen et al., 2019).

Blockchain systems also rely on standardized protocols and open-source software. Standardized protocols provide a common framework for the development and operation of blockchain systems, ensuring interoperability between different blockchain systems and enabling the easy integration of new nodes and applications(Moniruzzaman, Khezr, Yassine, & Benlamri, 2020). Open-source software allows for the transparency and accessibility of the underlying code, enabling developers to build upon and improve the technology(Abdulhakeem & Hu, 2021).

According to (Farouk, Alahmadi, Ghose, & Mashatan, 2020; Salah, Rehman, Nizamuddin, & Al-Fuqaha, 2019) the technology concepts behind blockchain, including cryptographic techniques, consensus protocols, standardized protocols, and open-source software, enable it to be a highly transparent, secure, and efficient technology for the storage and management of data. It has the potential to revolutionize a wide range of industries, including finance, supply chain management, and the construction industry, by improving the transparency, security, and efficiency of their operations. However, it is important to note that blockchain is still a relatively new technology and there are potential challenges and limitations to its adoption, such as the need for specialized hardware and software and the potential for scalability issues as the network grows.

Despite these challenges, the technology has the potential to fundamentally change the way we store and manage data, and it will be interesting to see how it continues to evolve and be adopted in the future(Broby, 2021).

A blockchain network consists of a series of interconnected nodes that communicate with each other to validate and record transactions(Atlam, Alenezi, Alassafi, & Wills, 2018). Each node maintains a copy of the blockchain, which is a chronological record of all transactions that have taken place on the network. The transactions are grouped into blocks, and each block is connected to the previous block using a cryptographic hash function, creating a chain of blocks(G. Chen, Xu, Lu, & Chen, 2018).

Based on (Needham & Schroeder, 1978) the transactions are secured using cryptography, which involves the use of cryptographic keys to verify the authenticity and integrity of the transactions. A public key is used to encrypt the transaction, and a private key is used to decrypt it. This ensures that only the intended parties can view the transaction.

Consensus algorithms are used to ensure that all nodes in the network agree on the state of the blockchain and that the transactions are valid. There are several different types of consensus algorithms, including proof-of-work, proof-of-stake, and proof-of-authority (Yang et al., 2019).

(Koulu, 2016; Sahai & Pandey, 2020)Smart contracts are self-executing contracts with the terms of the agreement between buyer and seller being directly written into lines of code. They can be used to automate certain tasks in a blockchain network and facilitate the execution of transactions based on predefined conditions.

Blockchain is a decentralized, distributed database that enables the secure storage and management of data. It is based on a network of computers, called nodes, which store and manage data by holding a copy of the entire database. This decentralized structure, along with the use of cryptographic techniques and consensus protocols, helps to ensure the security and integrity of the data, making it an attractive technology for a wide range of applications(Muzammal et al., 2019).

One of the main properties of blockchain is its decentralization. Unlike traditional, centralized systems, which store data in a single, central location, blockchain stores data across a network of computers. This decentralized structure helps to ensure the security and integrity of the data, as it is not controlled by a single entity and any changes to the data must be agreed upon by multiple nodes(Zhang, Schmidt, White, & Lenz, 2018). This property of decentralization also makes blockchain resilient to attacks and outages, as the network can continue to function even if some nodes go offline(Mougayar, 2016).

Another key property of blockchain is its immutability. Once data has been added to the blockchain, it cannot be altered or deleted(Politou, Casino, Alepis, & Patsakis, 2019). This is made possible through the use of cryptographic techniques, such as hashing and digital signatures, which ensure the authenticity and integrity of the data(Kavin, Ganapathy, Suthanthiramani, & Kannan, 2020). This property of immutability makes blockchain ideal for storing and managing data that needs to be reliable and trustworthy, such as financial transactions or legal documents(V. Chang et al., 2020).

A third important property of blockchain is its transparency. Data stored on a blockchain is visible to all authorized users, making it easy to track and verify the authenticity of the data. This transparency can improve the efficiency and trustworthiness of various processes and operations, such as supply chain management and voting systems(Marbouh et al., 2020; Niranjanamurthy et al., 2019).

In addition to these properties, blockchain also has the potential to improve interoperability and scalability. Standardized protocols and open-source software enable different blockchain systems to interoperate and easily integrate new nodes and applications(Uriarte & DeNicola, 2018). Additionally, the decentralized nature of the network allows for high scalability, as new nodes can be easily added as the network grows(Linn & Koo, 2016).

Overall, the properties of decentralization, immutability, transparency, interoperability, and scalability make blockchain a unique and powerful technology for data storage and management(Ratta, Kaur, Sharma, Shabaz, & Dhiman, 2021). It has the potential to revolutionize a wide range of industries by improving the transparency, security, and efficiency of their operations(Dutta, Choi, Somani, & Butala, 2020).

In the construction industry, blockchain technology can be used to improve transparency and efficiency in various processes. One potential application is in supply chain management, where the use of blockchain can help to track the movement of materials and reduce the risk of fraud and errors(Kouhizadeh & Sarkis, 2018). It can also enable real-time tracking of inventory levels and facilitate more efficient procurement processes. Project management is another area where blockchain can have a significant impact. By allowing for the secure and transparent exchange of information and documents between different stakeholders, blockchain can help to streamline communication and coordination in construction projects(Liu, Jiang, Osmani, & Demian, 2019). It can also facilitate the use of smart contracts, which can automate the execution of certain tasks and reduce the need for manual intervention, leading to cost and time savings(Zheng et al., 2020).

(J. Y. Lee, 2019; Mahmudnia, Arashpour, & Yang, 2022)Another potential use of blockchain in the construction industry is in payment systems. The use of blockchain can improve security and efficiency by allowing for the automatic execution of payments based on predefined conditions. This can help to reduce the risk of fraud and errors, as well as streamline payment processes and improve cash flow management. Additionally, the use of blockchain in construction can help to increase transparency and trust in the industry by enabling the secure and transparent recording of all transactions.

Overall, the adoption of blockchain technology in the construction industry has the potential to revolutionize the way projects are managed and delivered(Barima, 2017). It can help to increase transparency and trust in the industry, reduce the risk of fraud and errors, and streamline communication and coordination among different stakeholders. As the technology continues to mature and more companies adopt it, it is likely

that we will see an increasing number of innovative applications of blockchain in the construction industry(Hastig & Sodhi, 2020; Tripoli & Schmidhuber, 2018).

Table (1): Traditional, Centralized Data Storage and Blockchain Data Storage

	Traditional, Centralized Data Storage	**Blockchain Data Storage**
Definition	A type of data storage where all data is stored in a single, central location, typically managed by a single entity.	A type of data storage that uses a decentralized, distributed database to store and manage data.
Structure	Data is stored in a centralized location, typically on servers or in the cloud.	Data is stored across a network of computers, with each computer (called a "node") holding a copy of the entire database.
Data ownership	The entity that manages the central location (such as a company or government agency) typically owns the data.	Data ownership is distributed among the nodes in the network.
Data security	Data may be vulnerable to security breaches, as it is all stored in a single location.	Data is secure due to the decentralized nature of the network and the use of cryptographic techniques to ensure data integrity.
Data accessibility	Data is easily accessible to authorized users.	Data may be more difficult to access, as it is distributed across a network of computers and may require specialized software to retrieve.
Data integrity	There is a risk of data being altered or tampered with, as it is controlled by a single entity.	Data integrity is ensured through the use of cryptographic techniques and consensus protocols, which require multiple nodes to agree on any changes to the data.
Scalability	May be less scalable due to the centralized nature of the system.	Can be highly scalable due to the decentralized nature of the network.
Cost	May be less expensive to set up and maintain compared to a blockchain system.	May be more expensive to set up and maintain due to the need for specialized hardware and software.
Transparency	Data may not be transparent, as it is controlled by a single entity.	Data is transparent, as it is stored on a public, decentralized network and can be viewed by any authorized user.
Auditability	Data may not be easily auditable, as it is controlled by a single entity.	Data is easily auditable due to the decentralized nature of the network and the use of cryptographic techniques to ensure data integrity.
Interoperability	May not be easily interoperable with other systems, as data is controlled by a single entity.	Can be easily interoperable with other systems due to the use of standardized protocols and open-source software.
Role in construction industry	Traditional, centralized data storage is often used to store and manage data related to construction projects, such as project plans, blueprints, and contracts.	Blockchain data storage can be used to improve the transparency, security, and efficiency of construction projects by storing and managing data related to project plans, supply chain management, and project financing.

The table compares traditional, centralized data storage and blockchain data storage in the construction industry. Traditional, centralized data storage involves storing data in a single, central location, typically managed by a single entity. This type of data storage is structured such that data is stored on servers or in the cloud, and the entity that manages the central location typically owns the data(Abu-Elkheir, Hayajneh, & Ali, 2013). On the other hand, blockchain data storage is a decentralized, distributed system for storing and managing data. In a blockchain system, data is stored across a network of computers, with each computer holding a copy of the entire database. Data ownership is distributed among the nodes in the network, and data is secured using cryptographic techniques and consensus protocols(Kirli et al., 2022).

Table (1) also highlights some key differences between traditional, centralized data storage and blockchain data storage, including data security, data accessibility, data integrity, scalability, and cost(Jayabalan & Jeyanthi, 2022). Traditional, centralized data storage may be less secure due to the risk of security breaches, and data may be more difficult to access due to the decentralized nature of blockchain systems(Wang, Zhu, Ni, Gu, & Zhu, 2020). However, blockchain data storage can offer improved data integrity due to the use of cryptographic techniques and consensus protocols, and it can be highly scalable due to the decentralized nature of the network. In terms of cost, traditional, centralized data storage may be less expensive to set up and maintain compared to a blockchain system, which requires specialized hardware and software(Bhushan, Sinha, Sagayam, & Andrew, 2021; Croman et al., 2016).

Finally, the table notes that traditional, centralized data storage is often used to store and manage data related to construction projects, such as project plans, blueprints, and contracts(Xu et al., 2016). On the other hand, blockchain data storage can be used to improve the transparency, security, and efficiency of construction projects by storing and managing data related to project plans, supply chain management, and project financing(Hewavitharana, Nanayakkara, & Perera, 2019). Overall, both traditional, centralized data storage and

blockchain data storage have their own advantages and disadvantages, and the best solution for a particular use case will depend on a variety of factors.

APPLICATIONS OF BLOCKCHAIN TECHNOLOGY

(Jaag & Bach, 2017; Morkunas, Paschen, & Boon, 2019) mentioned that the blockchain has the potential to transform the financial industry by enabling faster, cheaper, and more secure financial transactions. For example, cryptocurrencies, such as Bitcoin, use blockchain technology to enable peer-to-peer transactions without the need for a central authority. This allows for faster and more convenient transactions, as well as lower fees compared to traditional financial institutions. In addition, the use of cryptographic techniques and consensus protocols helps to ensure the security and integrity of the transactions.

Another industry that is utilizing blockchain technology is supply chain management. Blockchain can improve the transparency and efficiency of supply chain management by enabling the tracking and verification of goods as they move through the supply chain(Rejeb, Keogh, & Treiblmaier, 2019). This can be especially important for industries where the authenticity and provenance of goods are important, such as luxury goods and pharmaceuticals. By using blockchain-based platforms, such as VeChain and Waltonchain, companies can track the movement of goods and verify their authenticity, helping to combat counterfeiting and fraud(Kayikci, Subramanian, Dora, & Bhatia, 2022).

BLOCKCHAIN AND SMART CONTRACTS

Smart contracts are self-executing contracts with the terms of the agreement between buyer and seller being directly written into lines of code. They can be used in a variety of industries and applications, including real estate, supply chain management, and healthcare. One technology that is particularly well-suited for use with smart contracts is blockchain(Unsworth, 2019).

Blockchain is a decentralized, distributed database that enables the secure storage and management of data. It is structured as a network of computers, called nodes, which store and manage data by holding a copy of the entire database(Muzammal et al., 2019). This decentralized structure, along with the use of cryptographic techniques and consensus protocols, helps to ensure the security and integrity of the data, making it an attractive technology for a wide range of applications(De Aguiar, Faiçal, Krishnamachari, & Ueyama, 2020).

By combining blockchain with smart contracts, it is possible to create secure, transparent, and self-executing contracts that can facilitate a wide range of transactions and processes(Christidis & Devetsikiotis, 2016). For example, a smart contract could be used to automatically transfer ownership of a piece of real estate from one party to another once the terms of the contract have been met. This could help to streamline the process of buying and selling real estate, reducing the need for intermediaries and saving time and money(Zheng et al., 2020).

Smart contracts can also be used in supply chain management to track the movement and authenticity of goods as they move through the supply chain. This can be especially important for industries where the provenance of goods is important, such as the luxury goods and pharmaceutical industries(Kshetri, 2018).

In the healthcare industry, smart contracts can be used to securely store and manage healthcare records(Amir Latif, Hussain, Jhanjhi, Nayyar, & Rizwan, 2020). By using blockchain-based platforms, such as the MedRec project developed by the Massachusetts Institute of Technology (MIT), it is possible to create a secure and interoperable system for storing and sharing healthcare records(Ekblaw, 2017). This can help to improve the efficiency and quality of healthcare by allowing healthcare providers to access the most up-to-date information about their patients.

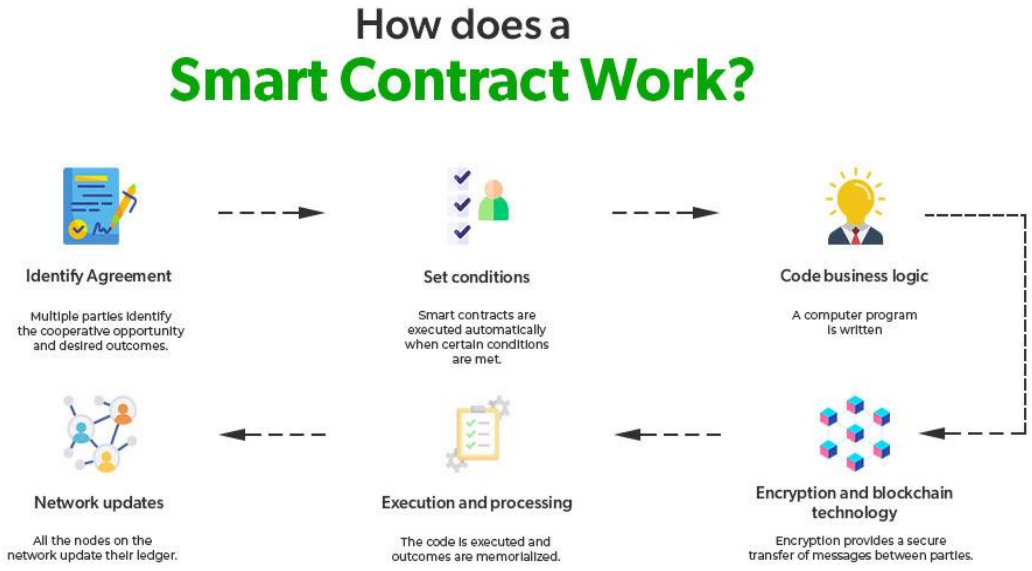
Overall, the use of blockchain technology in conjunction with smart contracts has the potential to revolutionize a wide range of industries and applications by improving the transparency, security, and efficiency of transactions and processes. By leveraging the unique properties of blockchain, such as decentralization, immutability, and transparency, it is possible to create secure and reliable systems for a wide range of applications(S. E. Chang, Chen, & Lu, 2019).

Table (2): Use of Blockchain Technology in Smart Contracts

Use of Blockchain Technology in Smart Contracts	**Benefits**	**Examples**
Secure, transparent, and self-executing contracts	Streamlines transactions and processes	Real estate, supply chain management, healthcare
Tracking and verification of goods	Improves transparency and efficiency	Supply chain management, luxury goods, pharmaceuticals
Secure storage and management of healthcare records	Improves efficiency and quality of healthcare	Healthcare
Automated execution of smart contracts based on	Reduces the need for intermediaries and	Supply chain management, real estate,

Use of Blockchain Technology in Smart Contracts	Benefits	Examples
predetermined conditions	manual execution	insurance
Secure and transparent voting systems	Improves the integrity and trustworthiness of voting processes	Elections, corporate governance
Secure and transparent property records	Improves the efficiency and reliability of property management	Real estate, land registry
Secure and transparent legal contracts	Improves the efficiency and reliability of legal processes	Legal agreements, intellectual property rights
Tracking and verification of project progress and payment	Improves transparency and efficiency of construction projects	Construction project management, supply chain management
Secure and transparent record-keeping for permits and licenses	Improves the efficiency and reliability of regulatory processes	Construction industry regulations, environmental regulations

Figure (2): Smart Contracts in Blockchain(Hooda, 2022)



Smart contracts are self-executing contracts with the terms of the agreement between buyer and seller being directly written into lines of code. They can be used in a variety of industries and applications to facilitate transactions and processes in a secure, transparent, and efficient manner(Kirli et al., 2022).

One technology that is particularly well-suited for use with smart contracts is blockchain. Blockchain is a decentralized, distributed database that enables the secure storage and management of data. It is structured as a network of computers, called nodes, which store and manage data by holding a copy of the entire database. This decentralized structure, along with the use of cryptographic techniques and consensus protocols, helps to ensure the security and integrity of the data, making it an attractive technology for a wide range of applications(Vivekanadam, 2020).

As shown in figure (2) the process of how a smart contract works in a blockchain technology can be described as follows:

First, the buyer and seller agree to the terms of the contract and the terms are coded into a smart contract. This smart contract is then uploaded to the blockchain network. Once the smart contract is uploaded, it is verified by the network of nodes. This verification process helps to ensure the security and integrity of the contract(Khan, Loukil, Ghedira-Guegan, Benkhelifa, & Bani-Hani, 2021).

Once the smart contract has been verified, it is executed once the predetermined conditions are met. For example, if the smart contract is for the sale of a piece of real estate, it may be executed once the buyer has transferred the payment to the seller.

(Dai & Vasarhelyi, 2017) mentioned once the terms of the contract have been carried out, they are automatically recorded on the blockchain. This helps to ensure the transparency and reliability of the transaction.

Overall, the use of blockchain technology in conjunction with smart contracts has the potential to revolutionize a wide range of industries and applications by improving the transparency, security, and efficiency of transactions and processes. By leveraging the unique properties of blockchain, such as decentralization,

immutability, and transparency, it is possible to create secure and reliable systems for a wide range of applications(Nawari & Ravindran, 2019b).

BLOCKCHAIN AND SUPPLY CHAIN MANAGEMENT (SCM)

Blockchain technology has the potential to significantly impact the way that supply chain management and circular economy systems are designed and operated. By utilizing the decentralized, immutable, and transparent nature of blockchain, it is possible to create efficient and secure systems for tracking the movement and authenticity of goods, as well as optimizing resource utilization and reducing waste(Nandi, Sarkis, Hervani, & Helms, 2021).

In the realm of supply chain management, one key application of blockchain technology is the tracking and verification of goods. By utilizing blockchain-based platforms and smart contracts, companies can accurately track the movement of goods and verify their authenticity, helping to combat counterfeiting and fraud(Helo & Shamsuzzoha, 2020). This is particularly important in industries where the provenance of goods is a critical factor, such as the luxury goods and pharmaceutical sectors(Atanasov et al., 2015).

As mentioned by (Banerjee, 2018; Kumar, Liu, & Shan, 2020) in addition to tracking and verification, blockchain technology can also be leveraged to optimize the efficiency and sustainability of supply chain systems. By using blockchain-based platforms to track the movement of goods and materials, companies can identify opportunities for waste reduction and resource conservation. This can lead to the creation of more sustainable and efficient supply chain systems, ultimately contributing to the establishment of a circular economy.Blockchain technology can also play a crucial role in the development of secure and transparent systems for tracking the reuse and recycling of goods and materials in a circular economy. By utilizing blockchain-based platforms to track the movement of goods and materials throughout the circular economy, it is possible to create a transparent and accountable system for ensuring that resources are utilized efficiently and effectively. This can help to reduce waste and improve the sustainability of resource utilization(Yildizbasi, 2021).

Overall, the use of blockchain technology in supply chain management and circular economy systems has the potential to greatly transform the way that these systems are designed and operated. By leveraging the unique characteristics of blockchain, it is possible to create secure, efficient, and sustainable systems for tracking the movement and authenticity of goods, as well as optimizing resource utilization and reducing waste(Bodkhe, Tanwar, Bhattacharya, & Kumar, 2022).

Table (2): Use of Blockchain Technology in supply chain management

Use of Blockchain Technologyin supply chain management	**Benefits**	**Examples**
Tracking and verification of goods	Improves transparency and efficiency, combats counterfeiting and fraud	Supply chain management, luxury goods, pharmaceuticals
Optimization of supply chain efficiency and sustainability	Improves efficiency and sustainability, reduces waste and improves resource utilization	Supply chain management
Secure and transparent record-keeping for permits and licenses	Improves the efficiency and reliability of regulatory processes	Construction industry regulations, environmental regulations
Tracking and verification of project progress and payment	Improves transparency and efficiency of construction projects	Construction project management, supply chain management

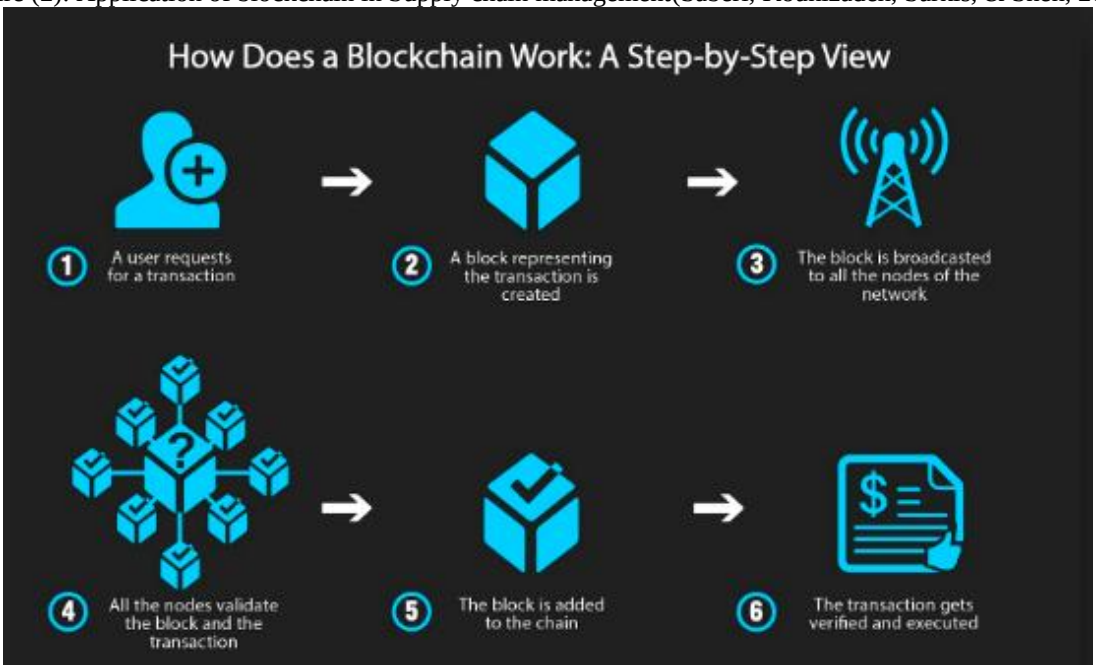
The incorporation of blockchain technology in supply chain management and the construction industry holds the potential to significantly alter the way these systems are designed and operated. By leveraging the decentralized, immutable, and transparent nature of blockchain, it is possible to create efficient and secure systems that enhance transparency, efficiency, and sustainability in a variety of processes and transactions(Qian & Papadonikolaki, 2020).

Table (2) above outlines a number of different uses of blockchain technology in supply chain management and the construction industry, as well as the benefits and examples of these applications. In addition to tracking and verification, blockchain technology can also be utilized to optimize the efficiency and sustainability of supply chain systems(Rana, Tricase, & De Cesare, 2021). By using blockchain-based platforms to track the movement of goods and materials, companies can identify opportunities for waste reduction and resource conservation. This can lead to the creation of more sustainable and efficient supply chain systems, ultimately contributing to the establishment of a circular economy(Bhat, Huang, Sofi, & Sultan, 2021).

Blockchain technology can also be employed for secure and transparent record-keeping for permits and licenses in the construction industry and regulatory processes. This can improve the efficiency and reliability of these processes by providing a secure and transparent record of the issuance and renewal of permits and licenses.Finally, blockchain technology can be utilized to track and verify project progress and payment in the construction industry. By using blockchain-based platforms to track the movement of goods and materials, as

well as the progress of construction projects, it is possible to enhance the transparency and efficiency of these processes.

Figure (2): Application of blockchain in Supply chain management(Saberi, Kouhizadeh, Sarkis, & Shen, 2019)



One key application of blockchain technology in supply chain management is the tracking and verification of goods. By utilizing blockchain-based platforms and smart contracts, companies can accurately track the movement of goods and verify their authenticity, improving transparency and efficiency while also combating counterfeiting and fraud. This is particularly important in industries where the provenance of goods is a critical factor, such as the luxury goods and pharmaceutical sectors. The ability to track and verify goods in real-time can also help to improve customer satisfaction and build trust with consumers(Hasan, AlHadhrami, AlDhaheri, Salah, & Jayaraman, 2019).

Another potential mentioned by (Esmaeilian, Sarkis, Lewis, & Behdad, 2020; Mastos et al., 2021) use of blockchain technology in supply chain management is the optimization of efficiency and sustainability. By using blockchain-based platforms to track the movement of goods and materials, companies can identify opportunities for waste reduction and resource conservation. This can lead to the creation of more sustainable and efficient supply chain systems, ultimately contributing to the establishment of a circular economy. The use of blockchain technology can also help to reduce the risk of errors and improve the accuracy of inventory management, leading to cost savings for businesses.

In addition to these applications, blockchain technology can also be utilized to facilitate the exchange of information and documents within a supply chain. By using blockchain-based platforms, it is possible to create a secure and transparent system for the exchange of information and documents, improving the efficiency and reliability of communication within a supply chain(Tijan, Aksentijević, Ivanić, & Jardas, 2019).

BLOCKCHAIN AND BUILIDING INFOROMATION MODELLING (BIM)

Blockchain technology has the potential to transform the building information modeling (BIM) and construction industry. By utilizing a decentralized, distributed ledger, blockchain can enable secure and real-time data sharing and collaboration among all stakeholders in a construction project, including architects, engineers, contractors, and owners(Srinath Perera, Nanayakkara, Rodrigo, Senaratne, & Weinand, 2020). This can streamline the design and construction process, reduce errors and omissions, and improve project transparency and accountability(Elghaish et al., 2021).

In BIM, blockchain can be used to store and manage all project data, such as 3D models, blueprints, and specifications, creating a single source of truth for all project information and reducing the risk of misunderstandings or miscommunication(Pradeep, Yiu, Zou, & Amor, 2021). Blockchain can also facilitate the automatic execution of smart contracts, allowing for automatic payment disbursements and other transactions based on predetermined conditions(Chaer, Salah, Lima, Ray, & Sheltami, 2019).

In the construction industry, blockchain can be used to track materials and equipment throughout the supply chain, ensuring they meet quality and safety standards. It can also be used to track and verify the completion of

tasks and milestones on a construction site, improving project tracking and progress monitoring(Li & Kassem, 2021; Regona, Yigitcanlar, Xia, & Li, 2022).

Overall, the use of blockchain technology in BIM and construction has the potential to increase efficiency, reduce costs, and enhance the quality of construction projects(Liu et al., 2019). However, it is important to carefully consider the implementation and use of blockchain in these industries, as it may require significant changes to existing processes and systems(Du, Pan, Leidner, & Ying, 2019).

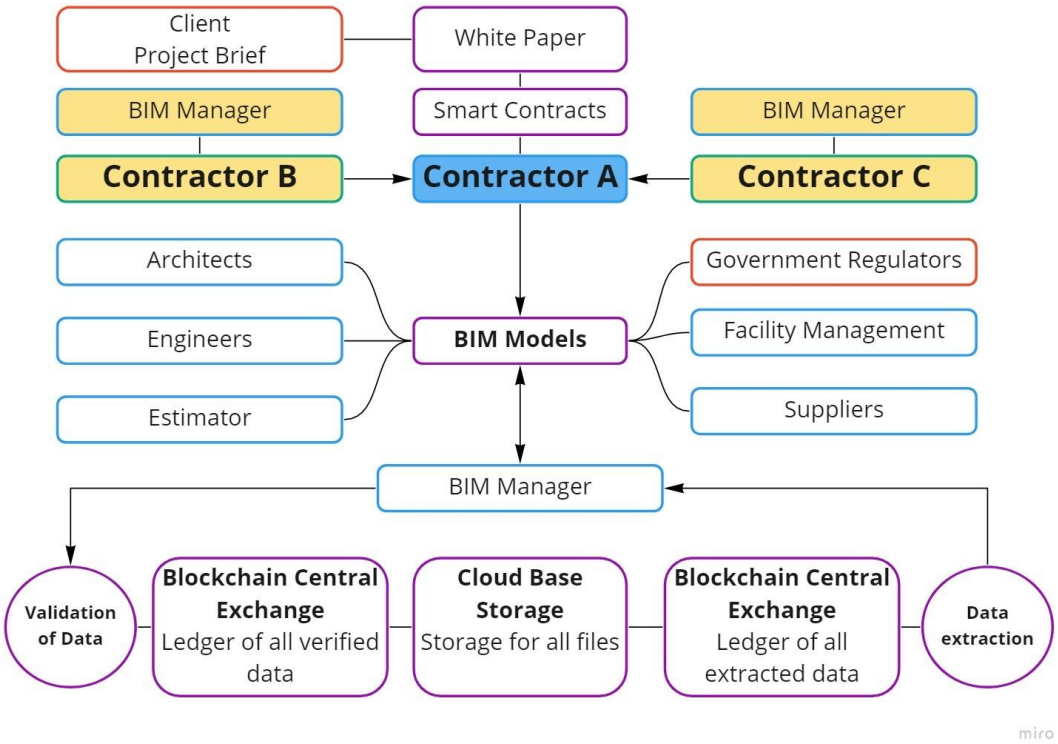
Table (3): Uses of Blockchain Technology in BIM

Uses of Blockchain Technology in BIM	**Benefits**	**Examples**
Supply chain management	Improved transparency and traceability of materials	Track the origin and quality of materials used in construction projects
Quality assurance	Enhanced quality control and compliance	Use smart contracts to automate quality checks and ensure compliance with industry standards
Asset tracking and management	Improved asset tracking and maintenance	Track and manage the lifecycle of construction equipment and assets
Collaboration and data sharing	Enhanced collaboration and data security	Use decentralized platforms to securely share and access project information among team members and stakeholders
Contract management	Improved efficiency and accuracy of contract execution and payment	Use smart contracts to automate the execution of construction contracts and payments
Predictive maintenance	Improved maintenance scheduling and reduced equipment downtime	Use blockchain and IoT technology to predict maintenance needs and schedule repairs for construction equipment

Table (3) outlines the various uses of blockchain technology in building information modelling (BIM) in the construction industry, along with examples of how it can be applied and the benefits it can provide.One use of blockchain technology in BIM is supply chain management. By tracking the origin and quality of materials used in construction projects, companies can improve the transparency and traceability of their supply chain(Shemov, Garcia de Soto, & Alkhzaimi, 2020). This can help ensure that materials meet industry standards and reduce the risk of delays or errors caused by faulty or low-quality materials.Another use of blockchain technology in BIM is quality assurance. Smart contracts can be used to automate quality checks and ensure that construction projects meet industry standards. This can help improve the overall quality of the project and reduce the risk of errors or non-compliance(Nanayakkara, Perera, Senaratne, Weerasuriya, & Bandara, 2021).

Asset tracking and management is another area where blockchain technology can be useful in the construction industry(Hewavitharana et al., 2019; Shojaei, 2019). By using blockchain to track and manage the lifecycle of construction equipment and assets, companies can improve their asset tracking and maintenance processes, which can help reduce downtime and increase efficiency.(D. Lee, Lee, Masoud, Krishnan, & Li, 2021) mentioned that collaboration and data sharing is another key area where blockchain technology can be applied in BIM. By using decentralized platforms to securely share and access project information among team members and stakeholders, companies can enhance collaboration and ensure the security and integrity of their data(Hang, Choi, & Kim, 2019).Contract management is another use of blockchain technology in the construction industry. By using smart contracts to automate the execution of construction contracts and payments, companies can improve the efficiency and accuracy of these processes, which can help reduce the risk of errors and disputes(Mason, 2017; Sigalov et al., 2021).

Figure (3): BIM Integration with Blockchain(Smith, 2020)



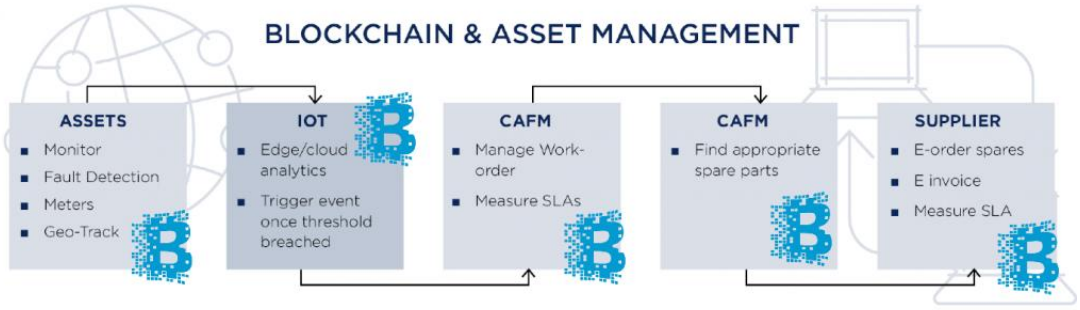
(Nawari & Ravindran, 2019a; Teisserenc & Sepasgozar, 2021)said that the integration of Building Information Modelling (BIM) with blockchain technology has the potential to significantly improve data security, transparency, and efficiency in the construction industry. By using decentralized platforms to store and access BIM data, companies can protect against data breaches and ensure that only authorized parties have access to the information. Smart contracts can also be used to automate the execution of BIM processes, reducing the risk of errors and improving the accuracy of the data.

Overall, the integration of BIM with blockchain technology has the potential to significantly enhance the benefits of BIM by adding a layer of security, transparency, and automation. It can help improve data security, transparency, and efficiency in the construction industry(San, Choy, & Fung, 2019).

BLOCKCHAIN AND FACILITY MANAGEMENT

The integration of blockchain technology with Building Information Modelling (BIM) or Building Maintenance System (BMS) can create a reliable and integrated system that can provide a complete history of a project and trace every detail of a building to its source(Lokshina, Greguš, & Thomas, 2019). This integration can also utilize smart contracts to automate processes such as placing a work order for maintenance and releasing payment to contractors upon completion. The concept of a Decentralized Autonomous Organization (DAO), governed by multiple smart contracts, can be applied to a building throughout its lifecycle, with smart contracts managing every stage from design and construction to operation, maintenance, and demolition in a cohesive and autonomous manner(Li, Greenwood, & Kassem, 2019). Blockchain technology is well-suited to support these complex interactions over time, similar to how a longitudinal health record functions in another industry(Al-Karaki, Gawanmeh, Ayache, & Mashaleh, 2019).

Figure (4): Facility Management and blockchain(Blundell, 2018).



Blockchain technology is a decentralized, digital ledger that records transactions on multiple computers in a network. Each block in the chain contains a record of multiple transactions, and once a block is added to the chain, the data it contains is unchangeable. This is achieved through the use of cryptographic techniques, which help to ensure the security and integrity of the data stored in the blockchain(Nagasubramanian et al., 2020).

BLOCKCHAIN AND SUSTAINABILITY

Material transparency in supply chain management has the potential to greatly improve sustainability in various aspects, such as whole life cycle cost, carbon emissions estimates, and raw material verification(Escobar & Laibach, 2021). For instance, the use of material traceability through blockchain technology can allow designers or users to make informed, sustainable choices by providing detailed information on the source of raw materials for products(Hader et al., 2022).

Based on (Nürk, 2019; Shojaei, 2019) typically, this type of information is provided by direct suppliers in the supply chain, but with the use of a blockchain platform, even indirect suppliers such as raw material providers to a prefabrication factory can also input their information for increased accuracy and verification. This process can provide consistent and structured asset information that can be used in decision-making during the design, procurement, and construction phases, as well as post-occupancy management of the facility.

In addition to improving material transparency, blockchain networks can also facilitate energy management on a grand scale. By tracking both energy consumption and production using a blockchain, a basis can be established for better supply and demand control, ultimately leading to the implementation of dynamic pricing for energy(Cole et al., 2019). This type of system can be particularly beneficial in the construction industry, where energy use is a major contributor to carbon emissions. By using blockchain to track and optimize energy use, construction companies can significantly reduce their environmental impact and improve their sustainability(Borowski, 2021).

III. CONCLUSION

The adoption of blockchain technology in the construction industry is still in its infancy, but it holds significant potential to address a range of challenges faced by this sector. In order to fully realize the benefits of blockchain, it will be necessary to establish common standards and templates for different application areas, and to integrate software with blockchain technology. As blockchain technology matures and relevant policy enhancements are put in place, it is likely that the construction industry will be able to leverage the technology to drive efficiency, transparency, agility, and cost savings. It is important to continue researching and exploring the potential applications of blockchain in the construction industry in order to fully understand and realize the benefits it has to offer.

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