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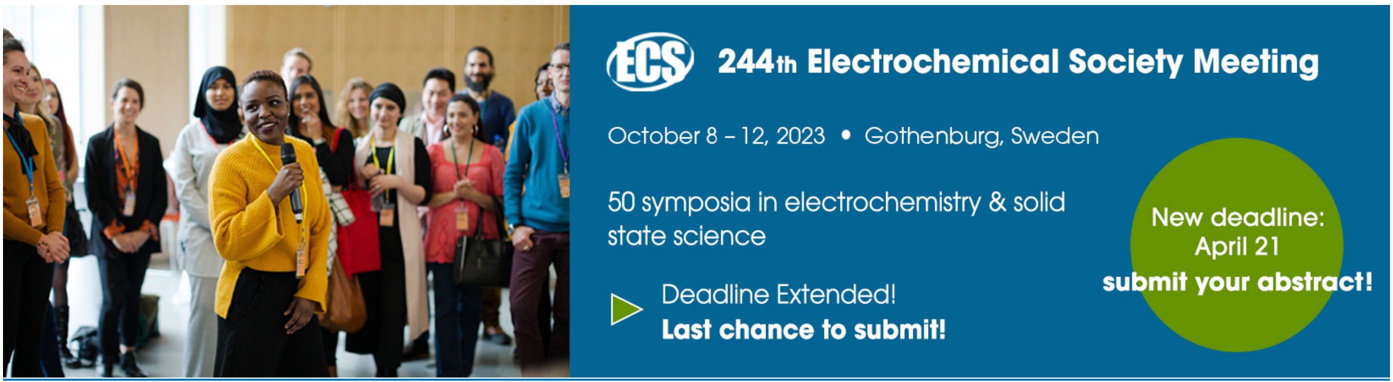

Integration of blockchain with emerging technologies in AEC industry: Merits and challenges

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Abstract. While in the last decade, digital tools and technologies have made their way into the construction industry, digital growth is still slow and incremental. The challenge is the consequential need for a collaborative and trustworthy environment with cooperation and concurrence among stakeholders. Blockchain technology holds promise and potential in providing this environment, infusing transparency and security in the mix. This study is thus motivated to explore the emerging information and communication technologies (ICT) in the architecture, engineering, and construction (AEC) industry and their integration with blockchain technology. Greater amounts of real-time digital information and automated systems with the security and transparency of blockchain could be a game-changer in planning and executing construction projects. It will affect not just the decision-makers at the top managerial level but will assist individuals down the line on-field to make decisions based on real-time data available to them.

Keywords: Automation, Blockchain, Construction management, Construction 4.0, Digitalisation, ICT.

1. Introduction

Construction activities, with their complex nature and volume, are becoming increasingly difficult to manage in the fast-paced global economy. Due to its fragmented and agile nature, the AEC sector faces numerous hurdles in project delivery, transparency, trust, integrity, and efficiency. As the world steps into the epoch of Industry 4.0, the construction industry also needs to transform and adapt to the emerging trend. Such a transformation to construction 4.0 is possible through a confluence of existing and emerging technologies with a promise to revamp the AEC sector [1]. With the pervasive use of technologies and tools like Building Information Modelling (BIM), artificial intelligence (AI), wireless sensors, three-dimensional (3D) printing, virtual reality/augmented reality, automated and robotic equipment, internet of things (IoT), and drones, the industry is at the cusp of digital transformation. The ever-increasing prevalence of digital information and data flooding has posed significant data security and provenance challenges. Thus, the industry must develop an ecosystem built on trust, transparency, and credibility. This study proposes blockchain technology to address the aforementioned challenges of security, authenticity, and veracity. The rest of the paper is organized as follows: Section 2 describes the emerging technologies that drive construction 4.0; Section 3 delves into the attributes of blockchain technology, blockchain mechanism, and its potential in the AEC sector; The merits and challenges in blockchain adoption are discussed in section 4; section 5 concludes the work with future scope.

2. ICT and digital construction

The fourth industrial revolution is driven by the emerging information and communication technologies (ICT). These technologies bring new possibilities and changing expectations for the construction industry as well [2]. Some of these technologies are discussed in this section with their applications in the AEC sector.

2.1. Internet of Things (IoT)

The IoT is a network of connected devices/things equipped with identifying, sensing, networking, and processing capabilities. They communicate with one another and other devices and services over the internet to monitor real-time parameters and provide visually informative end results [3]. This system of interrelated smart devices can transfer data over a network without requiring human-to-human or human-to-computer interaction. These objects/devices with sensors (cars, machines, cranes, engines, smartphones) exchange data among them and work based on specific protocols. IoT can be used to track machines, equipment, and employees on construction sites. The information collected is shared with building information management (BIM) systems to monitor the construction project closely [4]. Similarly, IoT can monitor the resource efficiency of projects by tracking supply and utilization.

2.2. Big data and cloud computing

Big data is a massive set of data, structured and unstructured, that can be further processed to extract information. This data is then processed and analyzed to understand patterns and algorithms using data analysis tools. While big data refers to the science of storing and analyzing exponentially growing digital data for providing valuable insights, cloud computing systematically stores data and programs using a network of remote servers, thereby helping to leverage big data analytics through anytime-anywhere access to data [5].

2.3. Artificial Intelligence (AI)

AI is replicating human intelligence via artificial technologies to invent intelligent machines. It emphasizes giving machines access to objects, categories, properties, and relations between all of them to implement knowledge engineering to make the machine work and act like human beings in every aspect. AI technology is used for improving performance and efficiency in construction projects. It is increasingly employed in project delay risk prediction, facility lifecycle, cost analysis, generating optimal building designs, and ensuring worker safety by constantly monitoring project sites [6]. AI-based neural networks have been used in decision making, dispute resolution mechanisms [7], safety management, progress monitoring, and 3D model reconstruction.

2.4. Digital Twin and BIM

A digital twin links digital representations and simulations with real-world data incorporating GIS, BIM, IoT, cloud computing, and AI. It combines a computational model and a real-world system designed to monitor, control, and optimize its functionality [8]. Through data and feedback, both simulated and real, a digital twin can develop autonomy capacities and learn from and reason about its environment. The digital twin is a digital model, but it can evolve into an autonomous system with less human intervention through AI-enabled design and control [1]. A digital twin can also be used for modeling, analysis, planning, and ensuring adherence to regulations. As the digital and physical models are constantly synced, any deviation can help firms take corrective actions and use the insights to monitor the project in real-time.

2.5. Augmented Reality (AR)

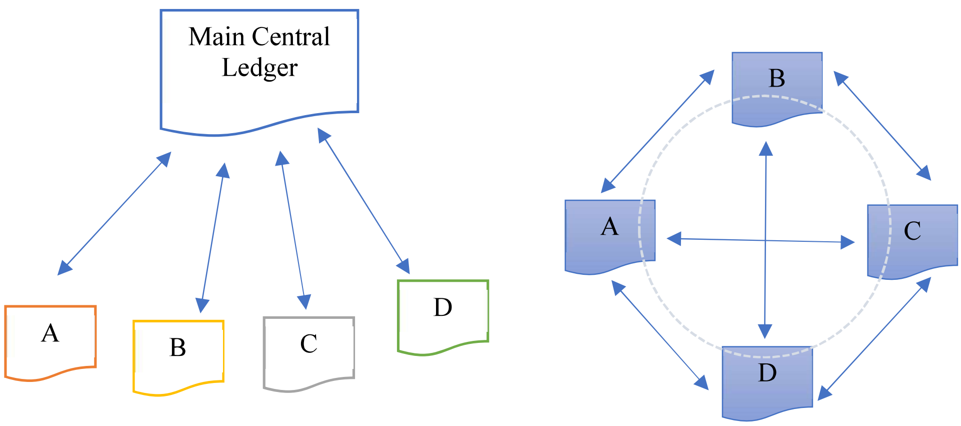
AR interacts with the artificial elements generated from digital devices and the real-life environment. It amplifies reality by overlaying virtual objects on top of the real-world environment. It helps users see and interact in a real environment with digital features. It provides tools for construction visualization and is being used in progress monitoring and defect detection in the AEC sector [6].

2.6. Blockchain technology

Blockchain has been one of the key technologies in the fourth industrial revolution [9] that records changes made to the information in real-time. It enables new forms of distributed software architectures that could enhance the security and transparency needed in the digital world. It has enabled a digital, global, and instantaneous value transfer without the need for a central instance through a decentralized network. The core features of the technology and its role in the AEC sector are discussed in the following sections.

3. Blockchain technology in the AEC sector

Blockchain technology is an advanced version of distributed ledger technology (DLT) that stores information chronologically in a decentralized fashion (figure 1). The information can be viewed/accessed by a network of users in real-time [10]. The transaction data is stored as a block in the network, with every block linked to its previous block through cryptographic hash values. The hash values are created by hash functions facilitating one-way encryption of plain text into 256-bit long unique cryptographic value [11]. Blockchain uses a consensus mechanism to validate the authentication of transactions stored in the block. It further uses smart contracts to enable real-time coordination of activities and transactions. Smart contracts are customizable executable codes that can be used to deploy business rules for the addition of blocks for an application. The characteristics of blockchain technology are discussed in the following sub-section.



Centralized record keeping, with each party maintaining their separate record based on the central ledger.

Decentralized record keeping, where all parties are connected to each other and all maintain the same record.

Figure 1. Centralized vs. Decentralised information exchange and record.

3.1. Key attributes of blockchain technology

The key attributes of blockchain technology are shown in figure 2. Blockchain takes the paper out of the picture, as with any digital technology. It is decentralized and not managed by a central authority but instead available to all stakeholders in real-time [12]. It is immutable so that the information cannot be changed or tampered with once published on the ledger. Blockchain has the potential to automate away the middle man (disintermediation) without affecting the workers on the ground. In a nutshell, we can say that "Instead of putting the taxi driver out of a job, blockchain puts Uber out of a job and lets the taxi drivers work with the customer directly" [13]. It resolves the construction industry's so-called 'trust problem' [14]. Instead of relying on a central integration point, it uses a common communication and governance protocol across an extensive network of untrusted participants [12]. The information sharing and consensus mechanism of blockchain technology is discussed in the next section with an example scenario from the construction sector.

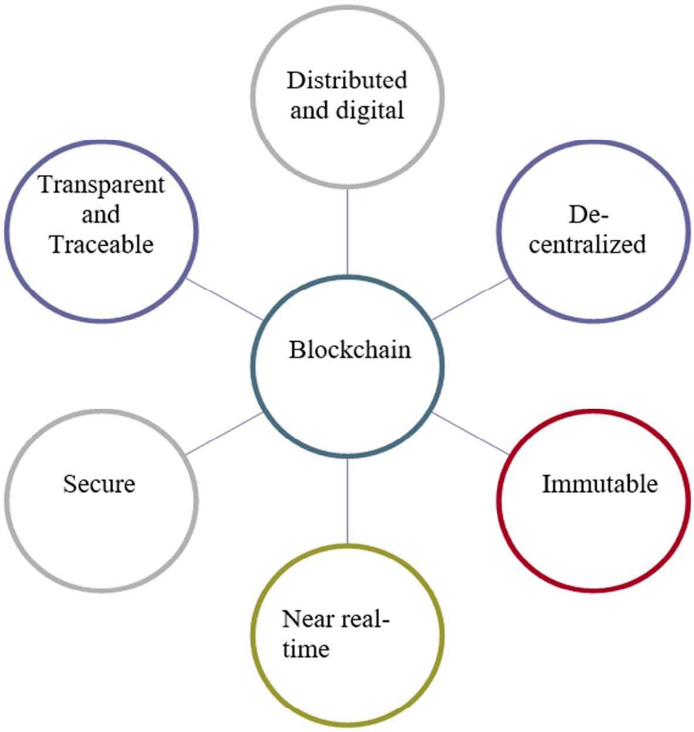


Figure 2. Key attributes of blockchain technology.

3.2. Blockchain information sharing and transaction mechanism: an example scenario

In this study, we propose a permissioned blockchain network for the stakeholders in a construction project. This type of blockchain ensures control and privacy in the network via the certificate authorities and cryptography-based authorization of the participants. In a permissioned network, the roles and responsibilities of the network participants (stakeholders) are defined, with access controls and rights provided based on their role in the network. Operations in a construction project like 'completion of work', 'payment execution', 'drawing submission', 'document approval', 'design check', and the like are termed as 'transactions' in the blockchain network. The transaction approval and information sharing mechanism in the blockchain network is shown in figure 3.

In order to conclude the transaction, the required network participants must verify and authenticate the completion. Consensus must be reached before the transaction is deemed fulfilled and written on the blockchain ledger, making the record immutable. The process is described stepwise below:

Step 1: When a contractor finishes a certain amount of work, she initiates a transaction proposal on the blockchain network. The transaction message is broadcasted to the whole network of connected computers (contracting parties and stakeholders) known as peers/nodes. The proposal includes information on the amount of work completed, the time of completion, the value of work, etc.

Step 2: A required number of peers must validate this transaction message for it to become an accepted transaction on the blockchain. This validation from all relevant stakeholders (client, consultant, and the like) remarkably improves the authenticity of the transaction. A consensus mechanism is used to validate the transaction.
Step 3: Once the consensus is reached in the network with the required peer signatures, the transaction gets pooled and ordered with other authenticated transactions into a block. This transaction completion is broadcasted to all the peers on the network.
Step 4: After the first block, a series or chain of blocks gets formed, creating a tamper-proof record for the whole network, and the ledger held by each peer is updated simultaneously in real-time
Step 5: The remuneration for the work completed is done based on pre-defined conditions, either as digital money transfer, online payment, or issue of a written payment obligation.
Step 6: Thus, an immutable record of the transaction with its origin and the factual real-time details of the transfer gets available to all peers as their individual copies of the blockchain ledger.

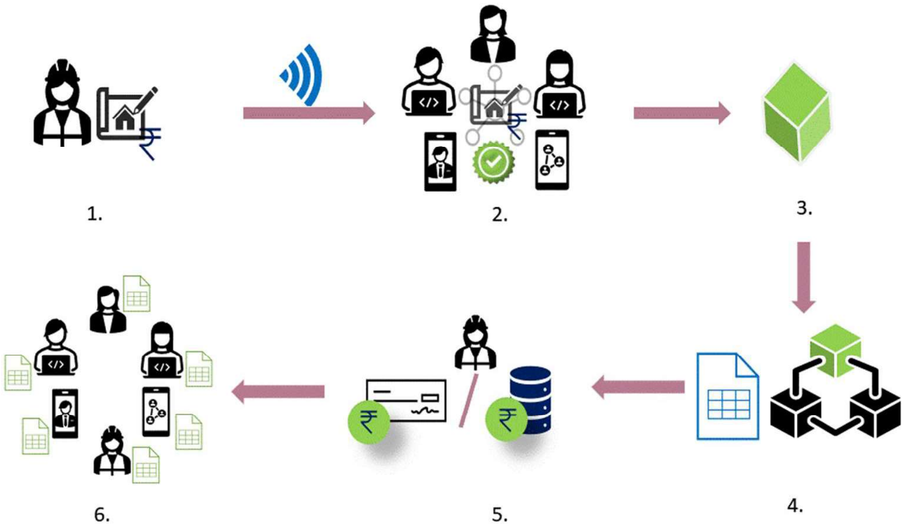


Figure 3. The transaction approval and information-sharing mechanism.

The ledger is updated simultaneously for all the peers, and hence, the information is shared among the different stakeholders. The peers can access the information stored on the ledger anytime by proposing the 'query function' for the ledger. This function makes it possible to trace the source of the digital information, ensuring transparency and accountability. The secure, decentralized, and collaborative blockchain environment helps the construction industry overcome the barriers faced in adopting and implementing the upcoming information and communication technologies. It offers a viable solution to the issues of automated information sharing, data provenance, security and privacy of digital documents, and credibility of data. Its role in the digitalization of the AEC sector is discussed in the next section.

3.3. Integration of Blockchain with information and communication technologies
Blockchain is a promising technology that can streamline the fragmented AEC sector benefitting all stakeholders, from the client and contractors to society at large. Its integration into other digital and automation tools in the AEC industry could bring transformational changes. Some of the tools and applications of blockchain technology in integration with the ICTs are:
- Decentralization of databases [14] [15]

Blockchain technology provides a reliable, decentralized, and transparent system to record, update and maintain the project database. It removes the need for a third party and serves as a platform for multi-disciplinary collaboration reducing bureaucracy and enhancing trust. A decentralized database allows all stakeholders to access it simultaneously without an intermediary. It manages security and privacy through cryptography rather than human administrators.

- Document and information management [16]
  In AEC projects, document and information management systems manage important project documents such as schedules, RFIs, and change orders. Blockchain technology can be leveraged in these systems to facilitate a transparent, immutable, and traceable system that securely integrates all the project information and local information silos, repositories, and communications.

- Construction payment automation [17] [18]
  Delay and uncertainties in progress payments are long-standing issues posing cash flow problems, leading to claims and disputes. The existing digital payment applications still rely on inefficient workflows and time-consuming processes. Even if computerized, they cannot support reliable automation of progress payments due to their reliance on centralized control mechanisms and lack of guaranteed execution. Blockchain-enabled digital wallets and project bank accounts can execute payments automatically based on the contractual conditions and work completed in a decentralized way. The payment information is shared and recorded at the project level transparently and securely.

- BlockIoT ecosystem [5] [19]
  Integrating blockchain with the IoT, radio-frequency identification devices (RFID), and smart sensors could influence the industry's landscape with endless possibilities. Drones can now deliver structural and land surveys, whereas smart sensors can collect data on the operation of an infrastructure asset throughout its whole lifecycle. The confluence of these with blockchain can enable real-time data collection and management. Such interconnected sensors can serve as a secured data source for construction managers.

- Digital twin [8]
  Distributed ledger technology can be used to support the digital twinning of built assets in a secured fashion. A digital twin of an asset provides valuable detailed information from inception to decommissioning, which can be accessed securely throughout the lifecycle of the asset using blockchain.

- Intelligent contracting [20] [21]
  Blockchain-based smart contracts are executable codes that can automate the clauses and conditions of construction contracts to create intelligent contracts. These contracts are legally binding agreements written in both machine-readable and natural languages. These smart legal contracts or intelligent contracts self-execute based on the contractual conditions reached.

- Integration with BIM [10]
  Blockchain can record changes in the BIM model throughout the design, construction, and delivery phases. It can provide a transparent, incorruptible, and secure sharing platform for the BIM model. The trace-back attribute of blockchain could help establish intellectual property rights and accountability in the design phase.

- Smart supply chains [22] [23]

The specific construction material (prefabricated structural steel unit, precast blocks) can be tracked and logged in real-time across the industry's supply chain using blockchain technology. It could provide all stakeholders with updated information on the material with standardized processes and a more transparent procurement operation. With blockchain-powered material provenance, digital tamper-proof approvals can govern the supply chain and improve on-site material, equipment, and labor streamlining.

4. Discussion
Digital construction is an integrated process, and blockchain technology provides a secure environment for this process. Some of the benefits of blockchain integration are listed below:

- Improved trust and security.
- Enhanced understanding among stakeholders of potential liabilities and associated ambiguities.
- Reduced risk by safeguarding critical records where a data loss could cost considerable amounts.
- Quick and accurate data tracking.
- Improved productivity by a reduction in downtime caused due to audit and compliance issues.

Despite the merits of blockchain, it faces some challenges that limit its wide adoption in the industry, such as:

- Very young technology: Blockchain is a nascent technology, and its applications outside the financial sector and cryptocurrencies are still in the early stages.
- Energy consumption: Substantial energy consumption by blockchain networks with computationally intensive processes may incur considerable costs.
- Scalability problems: With increased transactions, the blockchain tends to become bulky.
- Regulatory Uncertainty: There is a lack of regulatory clarity and standards on this technology [24].
- Cybersecurity: Though the fundamental technology underlying the blockchain has rarely been questioned on security grounds, implementing technology in businesses may not be watertight and may be subjected to security breaches [25].
- Lack of understanding of blockchain technology: Skill development and training is required to adopt the technology
- Ecosystem and culture change: The inertia of established systems and skepticism towards blockchain would hinder its widespread adoption. The entire ecosystem must change towards a more collaborative and cooperative way of working.

5. Conclusion
Blockchain has developed over the years from just a technology supporting cryptocurrencies to a technology disrupting business across sectors. It has a decisive advantage in providing a decentralized, transparent, robust, fault-tolerant way to store data with the potential to transform the way projects are executed. The integration of blockchain with emerging technologies in construction opens new avenues for research and application. The construction industry is set to transform in the coming years with the integration and confluence of these technologies at heart.

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