Blockchain Technology and the Future of Construction Industry in the Arab region :Applications, Challenges, and Future Opportunities

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Abstract:

The construction industry sector is one of the oldest sectors in the world and plays a major role in the development and advancement of societies. However, the construction industry suffers from low production and efficiency compared to other sectors for several reasons, including the different interests of the parties involved in construction projects and the fear of some of keeping pace with modern technological developments, in addition to the lack of confidence among the participants in the project, which are among the most important factors that reduce efficiency and productivity. In 2008, a technology emerged with the ability to overcome many of the challenges facing the construction industry, namely, the blockchain technology, which is associated with the famous cryptocurrency bitcoin. Its main purpose is to prevent changes to digital documents and preserve the data stored in them to prevent it from being modified. This technology has applications in many fields. The construction sector, especially in the Arab region, suffers from a lack of knowledge of the potential of this technology to help the construction industry in the digital age. The main objectives of this study were to explore the role of blockchain technology in shaping the future of the construction industry and to determine what this technology could contribute to the construction sector, especially in combination with building information modelling (BIM) technology. The researchers assumed that the adoption of blockchain technology in the construction industry would be a solution to a large portion of the current problems of the industry, which have slowed the adoption of BIM technology. Literature on the concept of blockchain technology and its applications to the construction industry was reviewed. Semi-structured interviews with Arab experts and specialists were conducted to collect information and qualitative data about the use of blockchain technology in the construction industry, with the aim of conducting a strength–weaknesses–opportunities–threats (SWOT) analysis. The views and experiences of the experts interviewed with respect to the potential advantages of and opportunities offered by the integration of blockchain technology and BIM technology in the construction industry in the Arab region were sought, in order to propose a conceptual framework to facilitate the automation of the processes and the stages of design, tendering, construction, maintenance, and effective management of the entire life cycle of construction projects.

Keywords: Blockchain technology - Building information modelling (BIM) - strengths - weaknesses – opportunities - threats (SWOT) analysis

Introduction:

Construction projects bring many disciplines together to design and shape the built environment. The construction sector is one of the largest industries in the world and a major driver of economic growth in all countries. However, the productivity and effectiveness of

the construction industry are often questioned, as its productivity has remained consistent for decades, while productivity has almost doubled and continues to improve in other industries during the same period, The construction sector needs to be more open to development to maintain its role in the development of the economies of countries. Digitization is a part of this development.

Research problem:

Despite the growing global interest in using blockchain technology; However, its spread in the construction sector in the Arab region is still very limited, and there are many challenges that hinder the widespread use of distributed ledger technology, which is the core of blockchain technology. The great challenge is the nature of the construction industry itself, which is still largely managed by traditional methods. Therefore, Blockchain technology (BC), smart contracts, supply chains, and decentralized applications are still not used effectively. The construction industry sector in the Arab region also suffers from a shortage. The knowledge of the potential of blockchain technology and the lack of experts in the potential of this technology and its ability to help the construction industry become more efficient, collaborative, and transparent in the digital age thanks to its ability to record, enable and secure huge numbers and types of transactions, where the integration of blockchain technology into the BIM environment can solve some of the current problems In the construction sector and enhancing its digital security in addition to introducing new areas of application and the successful transition from the proof-of-concept stage to the stage of full implementation of blockchain technology.

Research hypothesis:

The research assumes that the adoption of blockchain technology in the construction industry will be a solution to a large portion of its current problems, through the blockchain-based BIM system, integrated with a smart contract whose terms can be executed automatically, to provide a comprehensive platform for the effective management of entire construction projects.

Research aim:

The main objective of this study is to explore the role of Blockchain technology in shaping the future of the construction industry in the Arab region and what this technology can contribute and add to the construction sector when integrating into the BIM environment. in order to propose a future conceptual framework of this integration to facilitate the automation of the processes and the stages of design, tendering, construction, maintenance, and effective management of the entire life cycle of construction projects. The main research question is what are the benefits, applications, challenges, and future opportunities that blockchain technology can provide to solve the construction industry problems in the Arab region.

Research questions:

The main research questions are:

- what are the benefits, applications, challenges, and future opportunities that blockchain technology can provide to solve the construction industry problems in the Arab region?
- What are the advantages and potential future opportunities for the integration of blockchain technology and BIM?

Research methodology:

The study relied on the following sequential stages of the research methodology are presented in Fig. (1):

1- A descriptive-analytical approach in reviewing the literature on the concept of blockchain technology and its applications and a qualitative research approach to testing the application of the technology, using semi-structured interviews with eight Arab experts and specialists to collect more information and qualitative data about blockchain technology, its benefits, challenges, and future opportunities in the construction industry.
2- Formulating a SWOT analysis model for the effectiveness of the adoption of blockchain technology in the construction industry in the Arab region From The primary and secondary data obtained from the literature review and the interviews.
3- A deductive approach in exploring the opinions and experiences of the experts interviewed with respect to the potential future advantages and opportunities of the integration of blockchain technology and BIM technology to arrive at formulating a proposed conceptual framework for the integration of blockchain and BIM.

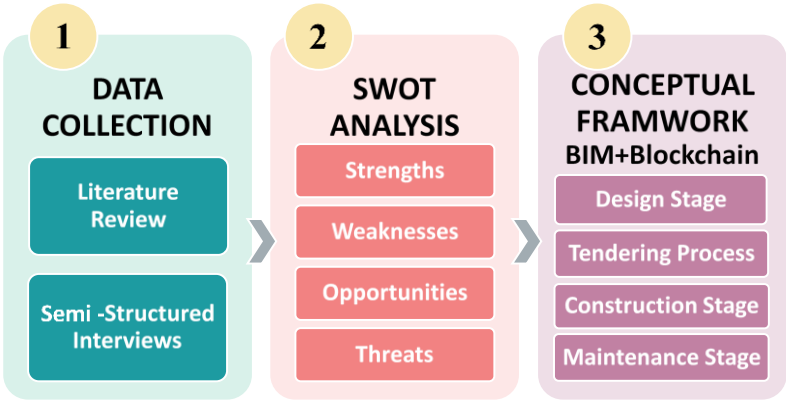

Fig. (1) The research methodology's stages[Author].

1- Blockchain Technology

1-1 The History of Blockchain

The ideas behind blockchain technology were first introduced in an article by Haber and Stornetta in 1991. The researchers proposed to create a timestamp for the security of digital documents. This timestamp would provide information about when the document appeared. More importantly, the timestamp would accurately indicate the order in which documents were created, preventing tampering [1]. In 1992, Haber and Stornetta further optimized the Merkle tree structure by incorporating it into the blockchain design. Thus, the efficiency of the overall structure was increased by making it possible to store multiple records in a single block. In 2008, an anonymous person or group of individuals under the pseudonym Satoshi Nakamoto published a whitepaper about a digital currency application called bitcoin [2], which was developed using blockchain technology as a solution to the problem of trust in the currency system [3] [4]. The purpose of this was to eliminate the middleman in the payment process. While bitcoin marked the beginning of new monetary technology, people have taken its basic technology, blockchain, and utilized it for purposes other than payments [5].

1-2 What is Blockchain?

Blockchain is a distributed database of data blocks. Each computer in a network shares the database and can create new blocks. The blocks contain the timestamp, the data to be stored, a numerical value called the hash, a “fingerprint,” and the hash of the previous block. Since each block created by this mechanism is interconnected, this technology has been named

blockchain [6]. Blockchain is a decentralized distributed ledger technology that reliably creates, validates, and records encrypted transactions of digital assets. In a blockchain, all transactions are stored in a single database. Each user keeps a copy of the database, and no component will cause the system to stop, in case it crashes, as with other databases [7]. Blockchain provides security, anonymity, and data integrity without the control of transactions by any third-party organization [8]. Blockchain maintains a collection of activities using a shared database, with all interactions cryptographically confirmed and allowed by all miners [9].

1-3 How Does Blockchain Work?

Blockchain is a record-keeping system that allows for the storage of an increasing number of entries in a digital ledger. Individual chunks of transactional data make up the ledger. These blocks are connected in a chain via cryptography, with each block inexorably tied to the block before it. When individuals talk about a blockchain, they usually mean the whole transaction history that the record-keeping system stores. The blockchain ledger can be modified but not added to, resulting in a reliable record of transactions and activity. A basic blockchain transaction is illustrated in Fig. (2) [10].

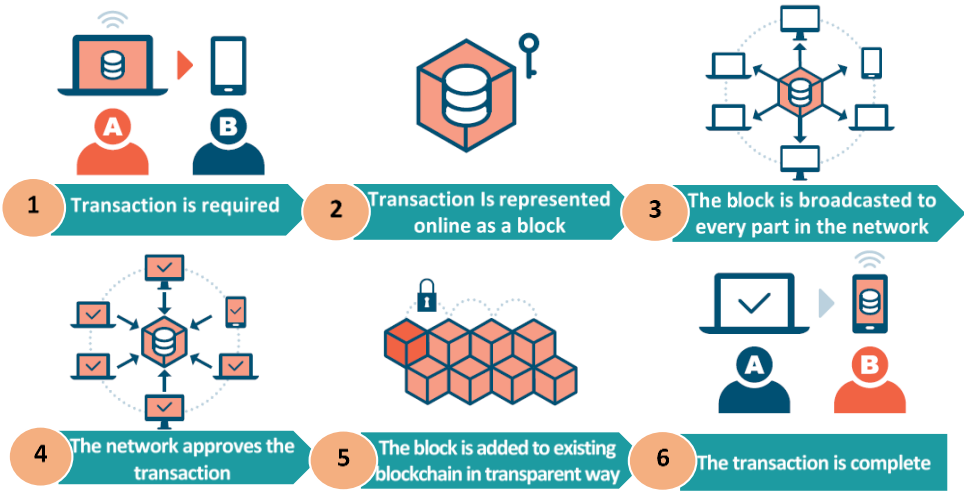

Fig. (2) The method for adding new transaction data to a blockchain ledger [10].

1-4 Blockchain Components

To understand blockchain technology, it is crucial to comprehend the components that go into the blockchain. Any blockchain system is made up of four important components: a node application, a distributed ledger, a consensus algorithm, and a virtual machine, as shown in Fig. (3). There are other components, but they all fit into one of these four groups.

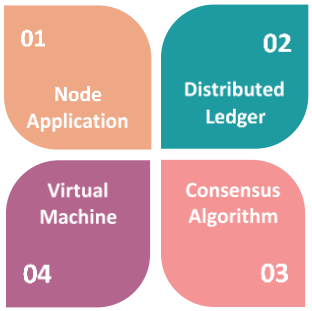

Fig. (3) Main components of a blockchain [Author].

1-4-1 Node Application

For a computer connected to the internet to participate in the blockchain ecosystem, it must first download and install a node application. To be a part of the blockchain network in the case of bitcoin as an ecosystem, each computer must run a bitcoin wallet program [11] [12].

1-4-2 Distributed Ledger

A ledger is a computer file that records data and transactions made by a user. A ledger is shared by everyone on the network as a database that is shared, duplicated, and synchronized across network peers. A distributed ledger's fundamental characteristic is its decentralization. Every entry in a distributed ledger includes a timestamp and a unique signature (created through cryptographic technology), making the ledger immutable and resistant to alteration [13].

1-4-3 Consensus Algorithm

Every transaction on the blockchain is validated and incredibly safe. That is not because it is decentralized. The presence of a consensus algorithm accounts for its security. A consensus algorithm is a procedure in computer science that is used to gain agreement about certain information across distributed computers. Blockchain technology takes advantage of this principle. The consensus algorithm was created for blockchain technology to establish stability in a blockchain network with various nodes. As a result, every incoming block in the network is fully vetted and safe [12].

1-4-4 Virtual Machine

The final logical component in a blockchain ecosystem is a virtual computer, which is a component of the node application. A virtual machine is a machine built by computer software. It is essentially an imaginary machine contained within a real machine. Virtual machines are used in Ethereum blockchain ecosystems. An Ethereum virtual computer (EVM) can comprehend instructions that aid in the management of the status of a digital contract. The EVM in a node program enforces the contract's rules and subsequently completes the transaction by issuing a digital token known as "ether." Because it is encrypted, this contract cannot be tampered with [14].

1-5 Block Structure

Blockchain is a collection of nodes that collect data about all transactions and are connected by the preceding block, in a manner similar to a distributed ledger. Every block header includes a hash, an authorized proof of transaction, and the previous block's hash values. The block structure must contain the information shown in Fig. (4) [9] [15].

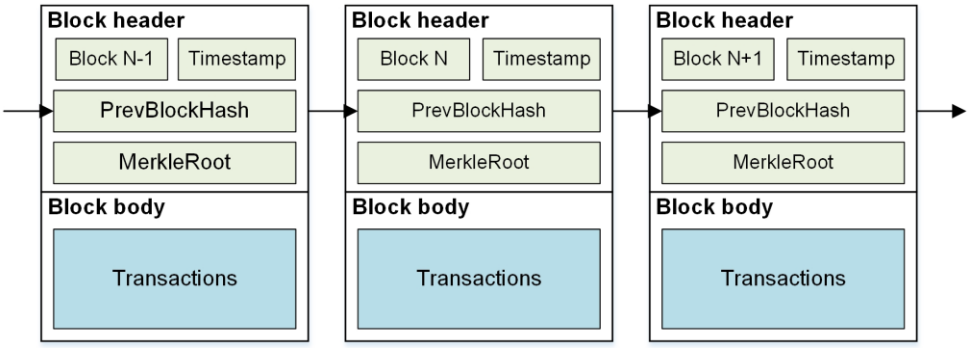

Fig. (4) Blockchain data structure consisting of three blocks [15]

- **Hash**: The main component of blockchain innovation is the hashing capability of a cryptographic system. Hashing is a cryptographic procedure that projects information of any size into a novel fixed-size yield. Hashing in blockchain guarantees to clients that the information communicated is not changed. Hashing is used in blockchain technology because of the security it offers [16].

- **Merkle tree**: In a hash tree or Merkle root, each node is represented as a leaf with a block labeled on it. This Merkle tree enables the user to securely and efficiently store massive data structures.
- **Timestamp:** A timestamp allows secure tracing of the creation or modification time of a document. This component is necessary [16]. It specifies the time and date when the document was created and remains unmodified. [9]
- **Nonce:** A nonce value is a four-byte value that starts at 0 and increases each time a hash computation is conducted [17].

1-6 Blockchain Types

It is a misconception that blockchains are accessible to anyone in the world. If that were the case, the privacy of the information stored in a Blockchain would be questionable. There are three types of blockchains: public blockchains, private blockchains, and consortium blockchains [18], as shown in Fig. (5).

1-6-1 Public blockchain

A public blockchain, also known as a permissionless blockchain, is open to anyone who wishes to join as a member of the network. All members of the network are allowed to access and read any transaction in the blockchain. No authentication is required for reading and writing to the blockchain [7].

1-6-2 Private blockchain

A private blockchain, also known as a permission blockchain, can only be joined by authorized participants. Network participation is by invitation, and certain rules assigned by the network creator or network initiator apply. Every transaction is recorded by approved parties or entities, rather than by all participants in the network [19].

1-6-3 Consortium blockchain

A consortium blockchain is a partially private blockchain solution without a single owner. Another term for such a blockchain is a hybrid blockchain because it combines characteristics of public and private blockchains [20]. A consortium blockchain has "participants" in groups that have privileges over the network. Consortium blockchain platforms are like private blockchains in that they offer many advantages of privacy, efficiency, scalability, and performance [9].

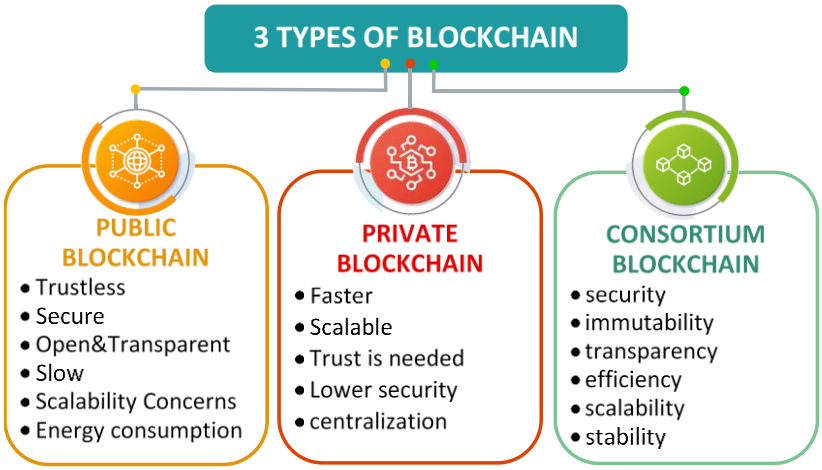

Fig. (5) Types of blockchains and their properties [Author].

2. Blockchain Application in The Construction Industry

The building construction process is a collaborative one, with construction projects involving a wide range of stakeholders and organizations. A building project's complexity creates issues for stakeholders and organizations [21]. For example, during the construction of the world's tallest skyscraper, the Burj Khalifa, more than 12,000 employees from more than 100 nations were employed. Considerable effort and resources are required to manage the supply chain, track work in progress, and manage schedules, costs, and payments for such large-scale projects [22]. However, the construction sector suffers from several problems, including low productivity, inadequate regulation and compliance, a lack of effective collaboration and information exchange, a lack of trust between stakeholders, and bad payment mechanisms [23]. As a result, the building construction process is based on high money and effort but is inefficient in adding value [24]. Blockchain technology has the potential to create stakeholder confidence, immutability, accuracy, and transparency in the building construction industry. Blockchain also has huge potential to transform the construction support process by allowing it to handle management-related difficulties. As a result, it is crucial to examine blockchain's potential uses in construction and the built environment [25].

2-1 Smart contracts and blockchain

A contract that is automatically fulfilled is referred to as a "smart contract." Such transactions take place between verified parties, are performed by computer code, and vary greatly in magnitude and complexity in the blockchain age. Fig. (6) shows how to use blockchain to carry out a smart contract in a construction project and the methods of money transfer from one party to another [26].

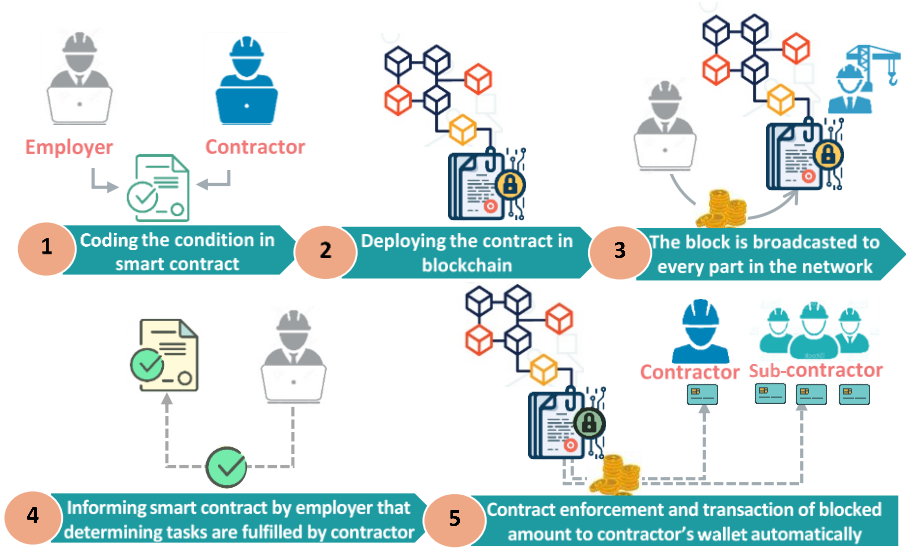

Fig. (6) A smart contract system for security payment of construction contracts [Author].

Many challenges related to transaction and documentation occur in construction project management. One of the primary causes of difficulties and disputes between parties is payment delay, also referred to as failure to pay on time [27]. Traditional contract development for a construction project is a complicated procedure that requires the agreement of several parties. Given the many types of contracts and transaction attributes, contract documentation is a time-consuming procedure. Although building construction is complicated and typically involves several partners, some jobs may be performed more effectively with automation. Smart

contracts, an essential breakthrough enabled by blockchain technology, may be valuable in building construction. Smart contracts have the potential to save time, reduce costs, build confidence among parties, ensure payment, facilitate quick transactions, and remove intermediaries. Smart contracts can limit or eliminate third-party influence while improving signature efficiency. Smart contracts offer various potential benefits to the building construction industry in comparison to standard contractual forms [21].

Payments can be accelerated using blockchain technology. Codes can be produced in blockchain blocks that use the "if-this-then-that" logic to automatically organize the required messages and payments. Payments may be made fast if the parties can explicitly agree on the payments and codify the payment terms. These codes are used to generate smart contracts, which are then stored on blockchains [7].

Fig. (7) depicts a basic example built on the Ethereum blockchain technology. The contract stipulates that if the project site temperature exceeds 40 degrees, the owner will pay a set amount of compensation to the construction contractor [25].

SOLIDITY CONTRACT SOURCE CODE

```
pragma solidity ^0.4.2;


contract MyContract {
    /* Constructor */
    address public contractor;
    uint256 public allowance;
    uint256 public temperature;

    mapping (address => uint) public balanceOf;
    event Transfer(address _from, address _to, uint value);


    function token(uint supply) {
        balanceOf[msg.sender] = supply;
    }

    function transfer (address contractor, uint256 allowance) {
        if (temperature < 40) throw;
        if (balanceOf[msg.sender] < allowance) throw;
        if (balanceOf[contractor] + allowance < balanceOf[contractor]) throw;

        balanceOf[msg.sender] -= allowance;
        balanceOf[contractor] += allowance;
        Transfer (msg.sender, contractor, allowance);

    }
}
```

Fig. (7) A smart contract example [25]

In general, with smart contracts; it can be guaranteed that the necessary funds and financing will be available to carry out the construction works; can protect main contractors, subcontractors, and suppliers from late payments, the bankruptcy of the parties involved in the project can be prevented, and an environment of trust can be created along with saving time and money.

2-2 Blockchain in Construction Supply Chain Management

A supply chain is a network of different processes of multiple firms connected upstream (suppliers) and downstream (customers) to deliver products or services to a final consumer [28]. The main challenge of a traditional supply chain is the lack of an open and reliable source of information throughout the supply chain. Due to a lack of transparency and traceability, customers and sellers have no real method to evaluate and confirm the actual value of the things they purchase.

In the construction industry, in particular, the supply chain is frequently addressed separately from design and workflow, which has an impact on the final product's quality [29]. Given the fragmentation of the building supply chain, it may be a suitable match for

the decentralized nature of blockchain. Blockchain might act as a neutral infrastructure to enable supply chain transparency and traceability, which are essential in this industry. Using a blockchain network for supply chain management, vendors and suppliers may simply exchange immutable licensed certificates to deliver certain goods and/or services, and buyers may validate such certifications and evaluate their quality by studying their past blockchain track records. This would make it easier for buyers and suppliers to develop trust between themselves [30]. More firms can be evaluated to engage as contractors or subcontractors based on accurate information and without the involvement of a third party [31]. Furthermore, blockchain can enable uniform reporting for all supply chain participants, including owners, contractors, and subcontractors. This would enable managers to keep track of the development of projects and logistics in real-time [18]. This would also facilitate near-immediate transactions using smart contracts; a tamper-proof ledger of manifests, departure times, and arrival times; and reductions in human error across the board thanks to more widespread automation [32] - Fig. (8).

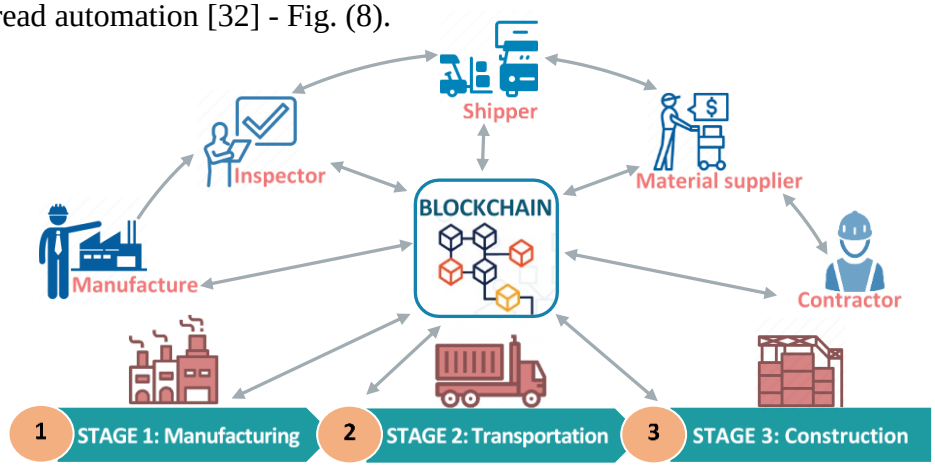

Fig. (8) Blockchain-based supply chain in construction project [Author].

2-3 Construction Management

Construction projects involve a large number of stakeholders and organizations, and the complexity of such projects results in professional and organizational fragmentation. Current construction management methods result in several challenges in terms of the trust, information exchange, and process management [25]. Blockchain technology has the potential to improve trust, immutability, accuracy, security, transparency, and many other aspects of construction management, allowing management challenges to be resolved easily. For example, construction drawings might be provided at various stages, and all partners must be notified. However, because the stakeholders work as independent entities, challenges can occur, such as identifying the most recent set of drawings, determining who issued the most recent drawing, and determining whether the drawings are consistent with approved architectural/structural/service designs. All of these problems can be handled by implementing a smart contract-enabled blockchain system, which allows the most up-to-date information to be updated and made available to the appropriate parties [33].

2-4 Equipment rental with blockchain

The concept of blockchain is a popular topic in the equipment rental field for many reasons, including the potential for eliminating the dependency on intermediaries, providing more transparency in equipment rental, and maintaining secure records of equipment usage, rental, and delivery. To examine a blockchain-supported equipment rental system in the construction industry as an example, we consider a contractor who chooses the crane he

wants to rent. The crane's identity is recorded in the blockchain. The contractor then chooses a rental option for the crane and connects the payment details for rental and insurance to a smart contract. Monthly payments, maintenance, and repair services are covered automatically. The operational status, including fault events, daily lifting loads, frequency of use, and electricity consumption can be monitored and recorded in the blockchain. Productivity in the use of the crane is increased as a result [25].

2-5 Waste management

The waste produced by the construction industry is recognized as a global issue that has a direct and detrimental influence on the environment [34]. As a result, proper construction waste management has become increasingly important, and accurate assessment of construction and demolition waste is one of the most important aspects of a successful construction waste management system's implementation [23]. Building and demolition waste is currently viewed as an unavoidable byproduct of the construction process. The majority of this waste is recyclable. Blockchain technology can be used to establish a standard waste management system that regards waste as a resource [35]. Furthermore, the application of smart technology for waste monitoring offers the potential for comprehensive solutions for achieving building project sustainability [33].

2-6 Property management

One of the most significant areas with the potential for blockchain technology to have a worldwide economic influence is the property sector. Blockchain may be used as an immutable distributed ledger that timestamps transactions, offers asset tracking, transfers ownership certificates, and keeps accurate, immutable history records [23]. Similarly, because there have been several reports of data manipulation in property ownership-related issues, blockchain technology is seen to be suitable for keeping a land register in a blockchain. In some countries, most properties are not recorded [36]. Several organizations around the world have proposed blockchain-based land registration as a solution to this problem [33].

2-7 Energy management

The distributed ledger technology offered by blockchain can be used to trade energy between individual producers and consumers at the local grid level [37]. A Blockchain network can also assist energy management at scale to achieve a smart grid. First, both energy consumption and production must be tracked using a Blockchain. This can then provide a basis for better control of supply and demand and ultimately true dynamic pricing for energy [33]. As the use of solar panels and other green energy sources is the latest trend in power generation, Blockchain technology can be used for transparency, traceability, and other benefits available to energy producers and consumers [35].

2-8 Sustainability

Material transparency, total life-cycle cost, and raw material verification all influence sustainability. For example, designers or consumers may make more sustainable choices by utilizing material traceability via blockchain to the source of any product's raw material. Typically, a blockchain-powered supply chain delivers the particular information sought by clients. A blockchain platform may enter the essential information into the database to not only supply the necessary information to direct suppliers but also provide more data to indirect suppliers, such as raw material suppliers [38]. This type of database is beneficial not just for decision-making during design, procurement, and construction but also for post-occupancy facility management.

3. Benefits and Challenges in Using Blockchain in Construction Industry

This section identifies and discusses the benefits and challenges of blockchain technology. Intermediation, automation, cost reduction, trust, and significant ownership are identified as benefits, while understanding of blockchain, its complex structure, initial costs, storage problems, and issues of privacy and security are identified as challenges- Fig. (9).

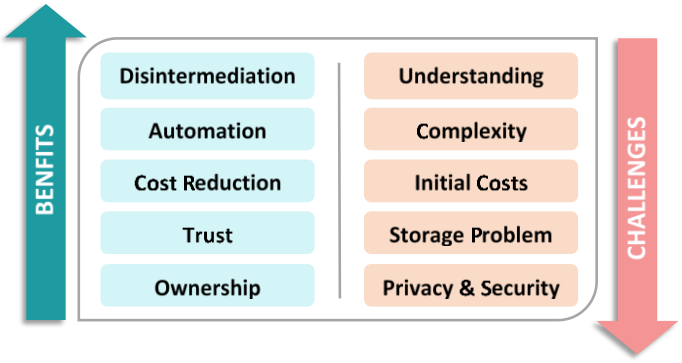

Fig. (9) Benefits and challenges of blockchain in the construction industry [Author].

3-1 Benefits

3-1-1 Disintermediation

Blockchain's potential to disengage the industry from middlemen is considered a key driver in industry-wide change. The core value of blockchain is that it allows a database to be shared directly, without a central administrator. This means less need for intermediaries within the blockchain process. Traditional central processes require agents, institutions, or additional technology to establish trust. This method is integrated into blockchain technology [39].

3-1-2 Automation

The working mechanism of blockchain technology can replace manual work tasks. Users can fully trust that transactions will be executed according to predetermined protocol commands, which removes the need for a trusted third party. By converting legal regulations and contract terms into computer codes, self-executing smart contracts are formed thanks to automation when the conditions are met [40].

3-1-3 Cost reduction

Firms are expected to be pragmatic in their transition to blockchain technology and approach it from the perspective of benefits and potential cost reductions. With the use of blockchain technology, reconciliation processes between organizations are simpler and more efficient, and significant cost savings are achieved by eliminating third parties, intermediaries, and central administration overhead. The net effect of disintermediation and automation is a reduction in costs for applications that can benefit from blockchain technology [41].

3-1-4 Trust

Blockchain technology can improve control and supervision, which can lead to greater trust. Blockchain effectively creates a sense of trust in people thanks to the protocols created and the technology it uses. Confidence in the process increases as a result of immutable record-keeping and the approval of the desired transactions through the consensus mechanism, whereby blockchain makes known the transaction history and changes made by the parties to the blockchain in a transparent manner that cannot be denied or challenged [39].

3-2 Challenges

3-2-1 Blockchain understanding

One of the major barriers to the adoption of blockchain technology is the lack of a solid understanding of the technology, its potential applications, and the benefits that it can provide [42]. The frequent use of blockchain with Bitcoin and its phonetic similarity has also contributed significantly to these misunderstandings. Blockchain should be understood as a technology rather than as a subfield of cryptocurrencies, and it should be obvious that its advantages are not restricted to those related to cryptocurrencies [43].

3-2-2 Complexity

it is possible to define a blockchain as the log of immutable transactions. Thus, any human error in a transaction is permanently recorded and cannot be reversed, which creates hesitation among users. Blockchain technology has also been described as too complex to engage the masses. Blockchain is still a new technology for most people. Lack of awareness and understanding of blockchain technology has led to difficulty in cultural adaptation to it and has hindered the spread of the technology [44]. Thus, “ease of use” is a critical issue in blockchain technology adoption.

3-2-3 Initial costs

The initial cost for blockchain technology adoption is quite high. Because of the computation-intensive nature of the technology, it may require extensive hardware. The adoption of Blockchain technology requires investment in new hardware and software for information gathering, which is costly for organizations and network partners [45]. Blockchain offers huge savings in transaction costs and time, but the high initial cost compared to traditional methods is a major barrier. Therefore, the adoption of blockchain-based solutions is often beyond the reach of small and medium enterprises with limited financial and labor reserves [44].

3-2-4 Storage problem

Blockchain technology records transactions in chronological order with timestamps [46]. Because of the consensus mechanism, transactions made at each node are stored. This results in the redundancy of data on the network. Redundancy is not related to the performance of a single node but rather to the total amount of computation required by the blockchain. As the size of the network grows and the number of transactions carried out with it increases, the number of records kept increases significantly, and therefore substantial storage resources are needed to maintain a copy of the blockchain [42].

3-2-5 Privacy and security

Blockchain is designed to provide transparent visibility of transactions to all users and ensure the suitability and immutability of transaction records. However, this feature is the reason that it was rejected by many potential users [33]. Some legacy institutions, such as governments, have to protect access to sensitive data for a variety of reasons. The transparency of blockchain technology stands in contrast to this requirement. The immutability, distributed consensus mechanisms, and privacy features of blockchain technology do not meet the requirements of some governments and financial institutions [47].

4. Integration of BIM and Blockchain

Building information modelling (BIM) is an intelligent three-dimensional (3D) model-based process that provides the insights and tools needed to more efficiently plan, design, construct, and manage buildings and infrastructure in architecture, engineering, and

construction. Although BIM is developing rapidly, much of the developed world uses Level 2 BIM, which is created on separate models by different disciplines. Level 3 BIM proposes that all parties work together on a single, shared model, aiming to create deeper collaboration, but this level of BIM is not yet commonly used. Blockchain technology can further improve BIM in the areas of security, accountability, transferability, and live data collection [48]-Fig (10). Linking between blockchain systems (e.g., Ethereum, Hyperledger) and BIM could offer new functionalities and track changes in 3D BIM models during the design and construction stages, making it easy for stakeholders to keep track of them and make the BIM process more secure and collaborative [23].

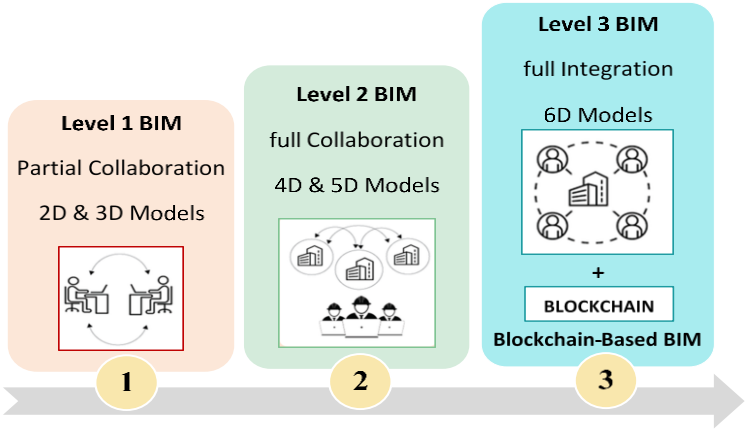

Fig. (10) BIM levels& relationship between blockchain and level 3 [Author].

The following are examples of Blockchain's potential for enhancing the BIM process and solving some of the current problems.

4-1 Design ownership

The BIM model creates legal challenges because it contains information from different parties, and each party will want to protect the intellectual property rights of their contribution [49]. Loss of control over design becomes a legal barrier to BIM implementation. As the design process progresses, different data entries occur within the BIM model, and the management of the model is very important in terms of allocating responsibility [50]. Using blockchain technology, the movements of various designs, models, and even families of objects in a BIM model can be clearly and transparently tracked, especially since there are many participants in BIM projects and each of them has different contributions to the design that are difficult to separate. In blockchain-based BIM, ownership rights for an asset, especially a digital asset, can be proven and tracked, and with digital currencies and smart contracts, ownership rights over designs can be transferred almost instantly and at a negligible cost [51].

4-2 Data security

The issue of data security has become very important in the digital world. BIM offers a multifunctional workspace that handles the planning, design, and construction phases of a building project to facilitate ongoing collaboration between all parties. In current usage, BIM uses a common data environment (CDE), which collects project information in a single repository to collect, manage, and distribute data for multidisciplinary teams [52]. All project members must therefore understand and comply with the cyber security rules [53]. Blockchain technology can provide a useful tool for managing and recording changes in the BIM model during the design and construction phases by keeping an immutable public

record of all changes in the model. Moreover, blockchain combined with the database capabilities of a BIM model can provide a vital, visible, and permanent "proof of trust" chain, creating value for the construction industry and its customers [31].

4-3 Contractual challenges

Construction contracts are designed to allocate and assign a balance of risk, responsibility, and reward. Getting the contract form right is an important prerequisite for the successful execution of a project. BIM is a contentious topic, much like conventional contracts [54]. Since BIM is not a traditional method, it would not be right to expect efficiency from BIM with traditional methods. Using smart contracts, each party in a project team can access the BIM model only with the permission of the smart contract, and each party's operations can be recorded in the blockchain. In this way, responsibilities and rights can be allocated effectively, and the information can be integrated into the blockchain database. Supporting BIM through smart contracts makes it possible to archive design files, control model access, ensure agreements, and follow all changes in the model. In addition, BIM, smart contracts, and blockchain integration can have a significant impact on construction activities and facility management [18].

4-4 Facility management

The integration of blockchain, BIM, and building maintenance systems (BMSs) provides a reliable and integrated system that can store the entire history of a building project and trace every detail of the building back to its source [31]. In addition, this integration can extend to the usage and post-use phases of a structure can be used with smart contracts to automatically issue a work order when maintenance is needed, and can automatically make the payment upon verification that the given work order has been completed in full. The concept of a decentralized autonomous organization (DAO) is promoted as an organization governed by multiple smart contracts. A DAO can be associated with a building throughout its life cycle, where everything from design and construction to operation, maintenance, and destruction is handled cohesively and autonomously via smart contracts [38].

5. Blockchain Opportunities in the Arab Construction Industry

A SWOT analysis was conducted to evaluate potential applications of blockchain technology in the construction industry in the Arab region objectively and systematically. SWOT analysis is one of the most popular methods of objective analysis of the strengths, weaknesses, opportunities, and threats of new technology. SWOT analysis highlights how to exploit external opportunities and reduce weaknesses and how protect against external threats. A SWOT analysis summarizes the strengths and weaknesses of the subject under study, along with the opportunities and threats faced. The strengths identified in a SWOT analysis of blockchain technology show how blockchain outperforms other traditional methods. In other words, the SWOT analysis highlights the features that make blockchain technology competitively advantageous. Among the weaknesses of blockchain are that other methods are more straightforward than blockchain. The assessment of opportunities and threats shows the potential benefits and drawbacks that the external environment can pose.

5-1 Methods for Collecting Data

A SWOT analysis is an effective approach to objectively assessing the effectiveness of adopting blockchain technology in the construction industry in the Arab region. The SWOT analysis relies on two main data sources, a literature review and interviews with experts, as described below.

- A literature review was conducted by reviewing magazines, books, conference proceedings, and other reliable sources on the concept of blockchain technology, its applications, benefits, and challenges to implementation in the construction industry.
- Semi-structured interviews were conducted with eight Arab experts. The sample size was determined based on a literature review of sample selection in qualitative research studies. The researchers decided to stop interviews after interviewing eight experts when they realized that the data collected repeated itself, which confirmed that the number of interviews was sufficient for the study. The interviewees were selected based on their experience in the subject of study by snowballing affect sampling. The sampling criteria included familiarity with blockchain technology, digital technologies, and BIM in construction, as well as professional experience in architecture, engineering, and construction. The geographical location of the interviewees was not limited; some of the interviews were conducted directly and some were conducted online. The participants were assured that their identities would be concealed to maintain confidentiality and that the results of the interviews would be used for scientific research purposes only.

Table 1: Summary of the interviewees' profiles, their backgrounds, and the types of interviews.

ID	Job title	Field of expertise	Years of Experience	Country	Interview type
P1	Founder of the first blockchain lab in Saudi Arabia.	Researcher and developer of emerging technologies	15	Saudi Arabia	Face to face
P2	Supervisor of the Blockchain Lab at Wadi Taibah Company	Developer and programmer of blockchain applications	10	Saudi Arabia	Face to face
P3	Chief executive officer for IT company	Information technology and blockchain expert	19	Bahrain	Online meeting
P4	Assistant Professor of Construction Engineering	BIM implementation expert	16	Tunisia	Face to face
P5	Head of the information technology sector in a bank	Financial technology and blockchain expert	20	Egypt	Online meeting
P6	Senior Architect and Project Manager	Architecture, Project Management, BIM, and Innovation	17	Saudi Arabia	Face to face
P7	BIM Project Manager & Coordinator	BIM implementation expert	15	Egypt	Online meeting
P8	Technical Director and Director of BIM at an engineering company	Review and preparation of BIM implementation plans and contractual documents	18	United Arab Emirates	Online meeting

5-2 Interview Questions

The interview questions were divided into four main categories:

- General questions to collect demographic data about the interviewees, such as nationality, educational level, country, job title, the field of experience, number of years of experience, etc.
- Questions to collect data from experts about the concept of blockchain technology and its applications in the construction industry in the Arab region.
- Questions intended to explore the opinions and experiences of the interviewed experts regarding the elements of the SWOT analysis of the use of blockchain technology in the Arab construction industry.
- Questions intended to explore the opinions and experiences of the interviewed experts regarding the potential future advantages and opportunities of integrating blockchain technology and building information modelling (BIM) technology.

An interview form was designed in Arabic and English to facilitate writing and organizing information during the interview, and the interviews were also recorded, with the consent of the participants, using a voice recording device. The audio files were later converted into transcripts to facilitate detailed analysis of the results of the interview sessions.

5-3 Data Analysis and Discussion

Table 2: Interview questions and results of analysis of responses.

5-3-1 Blockchain Applications in the Construction Industry in the Arab region
Q1 What is the blockchain concept and what is its application to building construction?
The interviewees unanimously agreed that blockchain technology is the most important innovative technology since the invention of the Internet and that it can be defined simply as a set of programming blocks that cannot be modified or tampered with once confirmed by the blockchain. It is a completely decentralized system, and its data is difficult to modify because of the high level of security it provides. This technology is now used in many fields: industrial, commercial, medical, media, investment, and many more .**Interviewee P1** added that blockchain technology can grow to become the cornerstone of record-keeping and data-keeping systems in Saudi Arabia and all of the Arab world, especially with the spread of digital currencies. **Interviewee P8** said that blockchain technology is the largest digital record system that allows the transfer of the origin of ownership from one party to another without the need for an intermediary, by easy and secure means. He added that on April 20, 2021, the United Arab Emirates adopted blockchain technology in the service of certifications Issued by the Ministry of Justice, such as documenting contracts and assets, which means providing its services more quickly and easily, in addition to maintaining confidentiality and privacy of data. **Interviewee P4** stated that Tunisia is the first country in the Arab region to have a state-run electronic payment system based on blockchain technology. Tunisia decided in 2015 to enhance its digital currency eDinar using blockchain technology based on the previous achievements of Tunisian Post, which is one of the main supporters of financial inclusion in the country. The Tunisian government has since collaborated with blockchain technology companies to roll out its first implementation of an entire digital payments ecosystem to provide financial services to underserved groups. **Interviewee P3** stated that the University of Bahrain has adopted blockchain technology, thus becoming the first educational institution in the Arab region to issue certificates to its graduates using this technology. Blockchain technology is used to ensure the issuance of documented digital academic certificates that cannot be forged and can be sent and shared with employers and universities. **Interviewee P5** believes that new and emerging blockchain technologies will be the basis for supporting and achieving a digital economy while ensuring effective protection and confronting the growing threats to data security and cybercrime in Egypt.
Q2 How can we implement blockchain in the Arab construction industry?
The interviewees agreed that the construction sector in the Arab region is witnessing strong investments in various projects, from the “Expo 2020 Dubai” and the “NEOM Smart City” to the “Riyadh Metro” project and “The New Administrative Capital” in Egypt. In all of these locations and construction projects, the architectural, engineering, and construction work system has adopted Internet-of-Things solutions to bring about a quantum leap in operations, rationalize costs, and increase productivity, efficiency, and worker safety. One of the most exciting new technologies in the construction sector in the Arab world is blockchain technology, using which data are verified securely at every step of procedures. The interviewees see potential applications of blockchain technology in building information modelling, and smart contracts, digital procurement, supply chains, and verification of the

identity of employees working on sites. **Interviewee P1** added that the greatest promises that blockchain technology offers for the Arab construction sector are the reduction of the risks associated with Internet-of-Things devices and ensuring the security of the process of integrating operating technologies with information technologies. For example, when deploying the Internet of Things, blockchain technology can decentralize network security decision-making and allow device networks to self-protect. Devices can also communicate with each other to achieve compatibility across the network and thus detect any unusual matter as soon as it occurs. **Interviewee P7** stated that Egypt has taken the first steps toward the introduction of the Internet of Things, as it is currently building the base for launching this technology in the country, which will of course facilitate the application of blockchain systems in the construction sector, as well as tens or hundreds of other services. **Interviewee P5** pointed out that Egypt has a great opportunity for digital transformation, especially after the COVID-19 crisis, and that there is an increasing trend to apply blockchain technology in the real estate sector. **Interviewee P8** added that the use of blockchain technology in Arab countries is not limited to financial services only and that the Smart Dubai Strategy, launched by Sheikh Hamdan bin Mohammed bin Rashid Al Maktoum, Crown Prince of Dubai and Chairman of the Executive Council, in October 2016 has as its goal to make the government of Dubai the first to be powered by blockchain technology, by providing all government services using this technology. The Smart Dubai Strategy has achieved remarkable successes in building the blockchain technology sector in Dubai. **Interviewee P5** mentioned the Aqar Chain firm, which is a real estate finance portal and the first local platform in the UAE that works with blockchain technology to represent real estate digitally. This platform is expected to revolutionize the way individuals invest in real estate using crowdfunding and digitally represented assets in a faster, smoother, safer, and more efficient way. **Interviewee P3** mentioned that the continuous progress made by the Kingdom of Bahrain in the field of information and communication technology and the adoption of Blockchain technology will play a critical role in improving the construction industry and enhancing sustainability, economic growth, and well-being of society. The Kingdom is moving steadily toward developing smart cities, which are areas that are built using advanced digital and engineering techniques to improve the economic and social conditions of the population.

5-3-2 Elements of SWOT analysis of the use of blockchain technology in the construction industry of the Arab region

Q3 What are the current strengths of blockchain technology for the construction industry?

The interviewees highlighted many strengths of blockchain technology in the construction and building sector, the most important of which are the following.

Productivity

The interviewees emphasized that in blockchain technology, transactions are done directly between two parties without the involvement of a third party, resulting in faster transactions. Furthermore, blockchain technology has the potential to manage smart contracts and corporate transactions automatically. As a result, each process is streamlined immediately, reducing the cost and time required for the process. **Interviewee P1** stated that blockchain technology can be used to implement point-to-point payments. As a result, third-party middleman connections can be eliminated, dramatically enhancing service efficiency and lowering transaction costs. In a world in which most interactions take place through intermediaries and are stored digitally, one of the most essential characteristics of blockchain technology, according to **interviewee P2**, is the realization of a core human need: the capacity to trust other people, institutions, and companies.

Automation	Automation of construction processes, according to **interviewee P6**, helps reallocate resources, reduce management duties, transfer risk, and decrease time and cost requirements. **Interviewee P3** said that, with the integration of building planning and design to the blockchain, needed verification procedures would be hastened, minimizing the need for numerous verifications by different players. As a result, there is no need for parties to be afraid or worried while using blockchain technology in building projects because automation will be used.
Confidentiality	According to **interviewee P6**, personal information is not normally necessary to register a blockchain account; only a private or public key is required, and the individual may use the public key, such as an account number, for all transactions without disclosing their identification information. **Interviewee P7** stated that anonymity in the construction business will be useful in many cases. For example, bids received in a tender procedure will stay anonymous until the requisite time has passed. To complete a transaction on a blockchain, the sender must use a private key to get access to bitcoin or data. Furthermore, for the sender to trade with any recipient, both the sender and the recipient must use the same public key. A consensus must be reached before a transaction can be recorded in a block, and a new block must be constructed and validated. According to **Interviewee P2**, blockchain also generates immutable transactions, which are tremendously useful to the construction sector because they reduce the use of phony digital signatures and double-spending.
Transparency	According to **Interviewee P1**, everyone with access to the system can see every transaction and its associated value in real-time, and no modifications can be made to these transactions. One of the major benefits of blockchain for small, medium, and large construction enterprises, according to **interviewee P4**, is transparency. The immutable history of blockchain is documented, giving traceability and auditability. **Interviewee P8** indicated that blockchain technology increases the transparency of any deal or transaction in a building project. Greater openness translates into increased accountability and better project supervision. A more transparent building process would result in greater alignment of industry and customer interests, as well as less conflict and risk. **Interviewee P 6**added that the transparency characteristic of blockchain makes supply chains more apparent and permits real-time tracking of items from the production phase to their arrival at the construction site.
Decentralization	Most of the interviewees agreed that one of the most important features of the blockchain system is that it is a decentralized system, meaning that information is not stored by only one entity, because each party in the network owns the information and can access the history of transactions but cannot change it. If a person transfers money to another party, the transaction moves in the form of clear data for all network participants. The transaction is decentralized, and users are not known by name but by tokens or codes. **Interviewee P3** emphasized that the main advantage of the blockchain system is the absence of a central administrator or centralized data storage mechanism, which enables blockchain technology to transform the construction industry into a decentralized industry, as it helps to reduce transaction costs, maintain more efficient records, and provide financial security, trust, cooperation, and solutions to many of the current problems in the financial management of the construction industry. **Interviewee P7** added that blockchain technology enables better tracking and management of contractual documents and the possibility of recovering money if the other party does not fulfil its commitment, and this is what the construction industry needs.

Q4 What are the weaknesses or disadvantages of blockchain technology at present that hinder its adoption in the construction industry?	
The interviewees pointed out several weaknesses that could hinder the expansion of the application of blockchain technology in the construction industry of the Arab region.	
Scalability	According to several interviewees, the full potential of blockchains can only be achieved through public blockchains, because private blockchains do not vary much in terms of data security from distributed databases, rendering them vulnerable to uninvited data alterations and manipulations. **Interviewee P2** mentioned that private blockchains are currently unable to connect. Nonetheless, senior management in the Arab construction industry may choose private blockchains for increased or centralized control of their blockchain applications over quicker transaction rates**.** According to **Interviewee P5**, although the construction industry does not involve as many transactions as the financial sector, other consensus algorithms that address the issue of scalabilities, such as PoS and DpoS, will be useful for the construction industry to adopt for many business applications without scalability issues.
Low Performance	**Interviewee P6** discussed the negative relationship between network security and network speed. Because data cannot be removed from a blockchain configuration, new transaction data are introduced in new blocks and linked to old blocks. These blocks are not playable. **Interviewee P5** argued that blockchain technology is not yet adequate for storing large data because of the low speed of processing large volumes of data. **Interviewee P2** stated that as a solution to this problem, only the most important data that should be on the blockchain should be recorded; all other data should be kept out of the register. **Interviewee P8** noted that a construction project involves a large amount of data, but only the data that needs to be processed on the blockchain can be recorded in the blockchain ledger. Space and time are issues because data are replicated on each network node. **Interviewee P 1**stated as an example that the Bitcoin blockchain requires more than 170 GB of storage on each network node.
Energy consumption	Most of the interviewees agreed that the total amount of energy required by network nodes, as well as the hardware cost necessary to validate new blocks, are quite high. According to **interviewee P1**, network nodes cost a significant amount of energy, however, the various consensus mechanisms contained in the Blockchain consume less energy. **Interviewee P5** gave an example of this, the amount of energy required to build the Bitcoin Blockchain is comparable to that consumed by small and medium-sized countries in a year, hence there are initiatives to lower the cost and amounts of energy consumed in the Arab region by producing them mostly from renewable sources.
Complex structure	**Interviewee P2** pointed out that it is extremely difficult to update and improve a blockchain's structure and design after it has been introduced. Cryptography is not customizable and must be employed throughout the lifetime of a blockchain. To put it another way, it is also difficult to repair errors or make other improvements. Blockchain technology is less adaptable than other technologies in this regard. According to **interviewee P4**, two of the most significant challenges to the adoption of blockchain technology in the Arab construction industry are the lack of awareness of the benefits of its use and the lack of skilled human resources who can deal with this complex technology, which is based on complex mathematical algorithms and requires powerful and sophisticated computers for its processors. The lack of a solid understanding of the construction industry, blockchain development, and their interfaces with law, engineering, and construction management is another major concern. Another concern is the immaturity of the legislation and laws about blockchain technology, which limits the attraction of investment to it.

Q5 What are the potential opportunities associated with adopting blockchain technology in the construction industry?	
According to the interviewees, the adoption of blockchain technology in the construction industry will open up many future opportunities for further improvements in data systems and information flows, the most important of which can be summarized as follows.	
New applications	**Interviewee P5** stated that blockchains will create a security layer above the Internet for all types of digital transactions in the construction industry. The biggest beneficiaries of Blockchain in this arrangement will be IoT-based applications, especially in facilities management, smart cities, digital twin generation, procurement, and material and physical/digital component supply management. **Interviewee P 6** assumed that, at the time when IoT and blockchain become more prevalent, the combination of these two technologies can enable safer and more secure construction sites throughout the Arab region. **Interviewee P4** sees blockchains being used in the future as a trusted mediator for two-way communication to support the establishment of decentralized shared data environments, such as blockchain-based cloud BIM platforms, for companies, towns, cities, and countries in the Arab region.
Digitization	All interviewees regard digitization as a significant strategic solution to established construction industry challenges (e.g., low productivity, low value, low safety, quality issues, frequent disputes, etc.). **Interviewee P4** believes that blockchain can advance the industry's digitalization strategy by addressing some of the fundamental digitization challenges, such as trust, transparency, data traceability, intellectual property rights, and record keeping. Although most interviewees confirmed that blockchain technology has the potential to facilitate smart contracts, procurement, generating secure digital identities and records for construction firms (proof of work), physical or digital asset tracking for the circular economy, process arrangements, and crowdfunding, **interviewee P8** stated that the technical opportunities may not be easily converted into economic opportunities.
Competition	**Interviewees P1 and P3** agreed that if blockchain-related efforts succeed, organizations that offer blockchain-based applications and services may gain a competitive edge. Smaller firms may compete with larger enterprises by developing trust-based trading/purchase frameworks on blockchains. According to **interviewee P5**, blockchain technology can dramatically lower project financing and transaction costs, allowing smaller firms to acquire greater market share. On the commercial front, blockchain can enable faster project finance and payment distribution, allowing firms to record more controllable cash flows.
Increased cooperation and trust	Most interviewees identified a lack of trust and limited cooperation between parties as common issues in the construction industry. As data become more transparent, increased cooperation and trust between parties is likely, and data come to be shared more freely. Reputation ratings in blockchain are potential reinforcers of strategic partnerships and increase collaboration throughout the supply chain. Cross-border trade can be made easier without the need for international exchange rates and border controls, especially when it comes to cryptocurrencies. However, blockchain also has the potential to interfere with the current international economic order. In cases in which contractors/subcontractors and the customer or the project are in different countries, using a blockchain with appropriate cryptocurrencies can reduce fluctuations in exchange rates and currencies. **Interviewee P6** explained that with rising attention to blockchain technology in the Arab region, strong government participation to legitimize its adoption is predicted in the near future. Because of the transparency achieved by blockchain, cross-border/regional capital movements and investments in the construction industry may pick up steam.

Q6 What are the potential threats to blockchain adoption in the construction industry in the future?	
The interviewees predicted that the expected high prevalence of blockchain applications in the construction industry in the Arab region would lead to many threats in the future, the most important of which are the following.	
Immaturity of technology	According to **interviewee P1**, blockchain is still in its early stages of growth and will need 3 to 5 years to overcome technical and regulatory challenges and risks before its impact and scalability mature, so the construction sector remains in a "watch and wait" state. **Interviewee P3** added that the adoption of blockchain technology in the construction industry will involve new roles, responsibilities, and expertise. The number of experts equipped to lead a blockchain implementation project on this topic is limited, so further development and understanding of blockchain technology are required to unlock its true potential. **Interviewee P8** stated that there are few real-life applications beyond feasibility, which may create a dilemma for organizations that want to understand the impact of technology on existing processes. The lack of new organizational policies necessary to clarify the use of blockchain technology can be difficult. The adoption of Blockchain technology can change or transform existing organizational cultures in the building sector.
Data privacy	When asked how prepared the construction industry is for the transparency brought about by blockchain and simplified/automated value transfers, the **interviewees** agreed that the need for information flexibility could be both a threat and an opportunity in the future because the immutable nature of blockchain will increase the sensitivity of organizations and supply chains to low-quality data. According to **interviewees P1 and P6**, public blockchains have no data privacy. Because there is no privileged user system, every user of the blockchain has access to all of the data of the blockchain, and anyone can join a public blockchain network without any permission. Most of the interviewees predicted that increased data transparency and point-to-point (P2P) transaction opportunities may irritate some third-party intermediary organizations or service providers who profit from the status quo in the construction industry, prodding them to weaken or control the technology.
Integration	**Interviewee P2** said that blockchain applications offer solutions that require significant changes to or complete replacement of existing systems, so construction organizations must procure or develop blockchain-based solutions that interact with their existing legacy systems or transform their existing systems to be blockchain compatible. **Interviewee P5** added that blockchain solutions may not initially provide all the functionality offered by existing systems and may require new systems that can be integrated with blockchain solutions to make the transition, and companies need to strategically plan what they are going to do. **Interviewee P8** expects that the existing digital divide between large and small companies may widen further, with smaller companies barred from participating in blockchain-based supply chain agreements if they are not sufficiently equipped.
legal status	**Interviewee P4** said that regulators are still catching up to blockchain innovation, which has hampered blockchain adoption in the construction industry. Because of a lack of government and regulatory backing in the Arab area, digital currencies that use blockchain have struggled to gain traction. **Interviewee P5** observed that the challenges that impede the application of blockchain technology in the Egyptian real estate sector are legislative, not technological, as there must be legislation to facilitate financial transactions in the real estate sector, which will contribute to the development of the economy as a whole. He further explained that this technology will contribute to enhancing clients' confidence, as it affords them the opportunity to know all the information about the real estate in question.

5-3-3 Integration of Blockchain Technology and Building Information Modelling	
Q7 What are the challenges facing BIM technology in the construction industry of the Arab region?	
The interviewees noted various challenges and obstacles that face the application of BIM technology in the construction industry in the Arab region. The constraints include important connections between the requirements of the design, implementation, and investment processes, including economic, technical, and cultural ones. **Interviewee P5** mentioned that humans usually resist change, and this technology requires major changes, as BIM technology requires more cooperation and forces people to deal with co-workers differently. This will lead to changes in the cultures of companies that have adhered to the standards imposed by the process of adopting this revolutionary technology. The transition to BIM technology software requires changes in mindsets about project modelling and project construction and requires the development of management processes. **Interviewee P6** added that the transition from traditional design systems to BIM technology programs requires the development and training of the current staff while ensuring the continuity of the production process. **Interviewees P7 and P8** identified various obstacles to the adoption of BIM technology in the construction industry, including the refusal by some people to use digital documents, the absence of laws regulating digital documentation processes, and their use in the courts in cases of litigation and technical disputes, and numerous current problems related to financial management.	
Q8 What are the advantages and potential future opportunities for the integration of blockchain technology and BIM?	
The interviewees emphasized that the construction industry may benefit greatly from blockchain technology by integrating it with cloud storage. A cloud storage system can be used to host all of the data for a project, and a blockchain system can be used to keep the metadata connected with any files added to the cloud. To provide complete transparency of file management, the blockchain should record file names, timestamps, and author data every time a file is uploaded or extracted for review. The cloud will become the one source of truth for all project data. **Interviewee P3** noted that every single update to the model is precisely recorded, boosting the reliability, traceability, and ownership of the information and improving collaboration and trust among the parties involved. **Interviewee P4** stated that the integration with blockchain technology ensures data integrity and can generate a unified format in favour of transparent, open sharing, guaranteeing cybersecurity for the transaction of financial services in the construction industry. Finally, the interviewees mentioned many potential future possibilities for this integration throughout the construction process and project life cycle.	
Design Stage	Most interviewees anticipate that the distributed ledger in a blockchain-based BIM shared by parties will aid in the planning and design phases, providing a good understanding of project information and identifying who is responsible for each activity. A client's project requirements and standards and any design packages to be produced can be recorded in the blockchain and therefore be accessible to all contractual parties. The implementation of a blockchain enables the creation and deployment of smart contracts and transparent and trustworthy sharing of information to facilitate the progress of the design stage. **Interviewee P2** mentioned that smart contracts may be used to manage payments to design teams in this first stage, with funds automatically released at the end of each project verification cycle. **Interviewee P7** added that a BIM model can be created using the client's standards, and the compliance of each design stage can be checked using code and model checking tools. Smart contracts are automatically completed by releasing the appropriate fee based on verification findings.

Tendering Process	**Interviewee P4** emphasized the importance of the blockchain ledger for both the customer and the participants during the tender stage. For example, the first party saves all tender papers and assessment criteria in an immutable format. With a blockchain-based BIM, participants are guaranteed maximal fairness in information sharing and equal ease of access to all project elements. Similarly, participants can deposit tender bids on the platform, making them irreversible and transparent to everyone. **Interviewee P6** added that smart contracts developed based on assessment criteria provided by the client can be used to evaluate and compare bids. The tender assessment results can be compared transparently, ensuring an unambiguous choice of the winner.
Construction Stage	The majority of interviewees thought that a blockchain-based BIM platform could be utilized to both monitor and regulate the development of the supply chain during the construction phase of a project. The BIM model linked to the work could be updated in real-time as the work progressed, documenting the evolution of the activities identified in the program of work and the parties accountable for each activity. Similarly, information related to the supply of materials and products to a construction site could be recorded in the blockchain, ensuring complete transparency over the materials used. As **interviewee P7** observed, smart contracts can be configured based on both milestones defined and the delivery deadlines, with the information recorded in the blockchain allowing smart contracts to be automatically activated and payments to task creators to be released upon completion of each operation and fulfilment of each transaction. This environment, which ensures payments, offers motivation for work teams to perform each assignment in accordance with contractual conditions.
Maintenance Stage	**Interviewee P1** commented that all information connected to building system maintenance tasks may be stored in a blockchain. The gathering of information linked to the functioning and maintenance of the equipment allows for the regularity of the services supplied by the contractors to be monitored. Smart contracts can be programmed depending on the regular maintenance tasks that must be completed. When each scheduled action is completed, the data is submitted and updated in the model by the teamwork, and the smart contracts automatically give the pay-outs. According to **interviewee P6**, the effectiveness of these technologies increases for smart buildings, where facilities may automatically detect the performance of regular maintenance and services by predefined tasks. In this manner, the activity-related information is automatically correlated with the real item, which exists in the model, and then recorded in the blockchain. **Interviewee P8** stated that the greatest promises of blockchain in the construction sector are its potential to decrease the dangers of IoT devices and to ensure the security of the process of merging operational technologies with information modeling technologies. **Interviewee P7** gave an example in the context of the Internet of Things: blockchain technology can decentralize network security decision-making, allowing device networks to self-protect. Devices can also communicate with each other, thus detecting any unusual matter as it occurs.

5-3-4 A SWOT analysis model

The primary and secondary data obtained from the literature review and the interviews with experts present a broad and detailed assessment of the capabilities and potential applications of blockchain technology in the building construction industry. A model for SWOT analysis can be formulated for the effectiveness of the adoption of blockchain technology in the construction industry in the Arab region - Fig. (11).

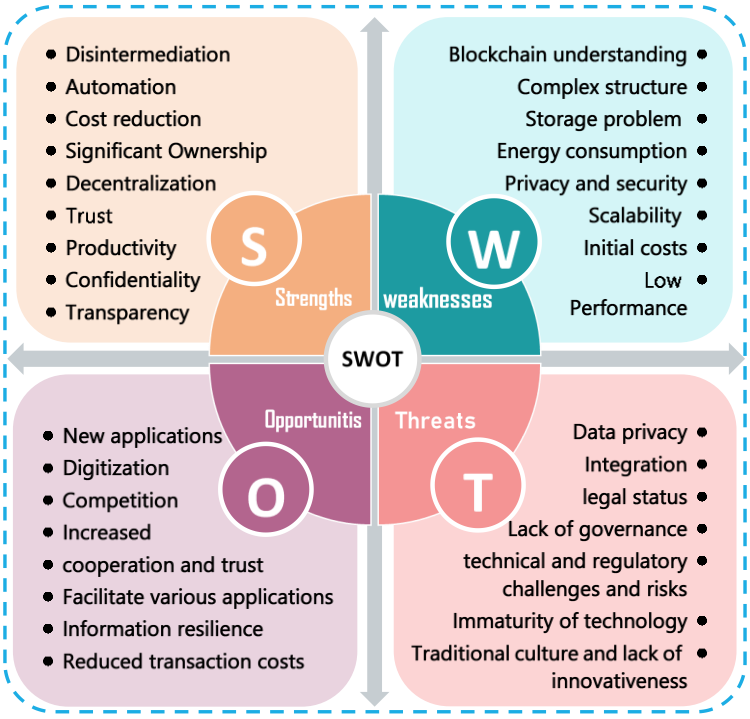

Fig. (11) model for SWOT Analysis of implementation blockchain technology in the construction industry in the Arab region [Author].

- In the SWOT Analysis, When we look at the structural features that make blockchain technology attractive in the construction industry ; We see that it is not dependent on an authority due to its decentralized structure, that it automatically implements the contract according to predetermined conditions with its automation feature, that it provides users with the opportunity to monitor the transaction history with its transparency feature, and that all transactions made are accountable. The automation feature of blockchain technology is noted in both its support and strengths. Similarity in supports and strengths needs to be differentiated. Not deleting any data saved in the blockchain system can also help detect malicious attempts.
- On the other hand, high energy consumption, the problem of working at the same efficiency as the capacity increases, performance and some issues in the consensus mechanism are the weak areas of blockchain technology.
- Since blockchain is a new technology compared to other technologies and there is still a lot of wrong or incomplete information about it, potential users can be expected to be more cautious about this new technology. In open blockchain systems, the fact that the data is secure but visible to everyone can be perceived as another threat. Changes in the exchange rates of cryptocurrencies may make investors think. The uncertainty of whether the users' already established systems will be integrated into the blockchain may prevent users from investing in this technology. The fact that there is no clear legal regulation yet may be another factor that will make users think.
- Blockchain technology also contains a number of opportunities. For example, in addition to the fact that technology has a structure that can solve the problem of cooperation and trust in the construction industry, small-medium-sized companies that adopt blockchain technology may have the opportunity to compete with other large-scale companies due to the increasingly competitive nature of the industry. In today's digitalizing world, being present with the advantages of blockchain in the Arab construction industry can help in the

digitalization process. In addition, the opportunity to facilitate the adoption in society can be created by preparing user-friendly applications for the complex seemingly complex structure of blockchain.

6. A conceptual framework for future integration of blockchain and BIM

Based on the results of the literature review, expert interviews, and the SWOT analysis, a framework for the integration of blockchain and BIM technology can be prepared and formulated. Fig. (12) illustrates the development of operational processes aligned with the roles and responsibilities of stakeholders and the construction project life cycle. The basic principle of using a blockchain-based BIM system is to improve transparency and file traceability, as all data transactions are recorded and documented. The proposed future conceptual framework depends on the following:

6-1 inputs

- Before the start of the project, the BIM manager, client, and project leaders will review and agree on deliverables, BIM standards, and information exchanges.
- Provide an internal blockchain cloud storage system that is incorporated into the company database and records and stores the BIM Standard for each project, which may be customized for different project types. Once the project standards are finalized, they will be saved in the database and sent to each employee as a smart contract that outlines the project's particular criteria. Through the smart contract, the employee would examine and certify their needed contribution to the project, which would describe software needs, data sharing internally and externally, and naming convention, among other things.
- Entering big data and ensuring that the correct information is linked during the project period through cloud storage supported by blockchain technology, where the cloud will keep all project data, and the blockchain system will store metadata associated with all files added to the cloud.

6-2 Process and Data Management

- The blockchain will record files names, timestamps and author details every time a file is upload or extracted for review to ensure clear transparency of file management. The cloud platform will only offer a user the ability to view files and not alter them, this will mean the cloud becomes the single source of truth for all project data. The cloud platform will also have the capacity for a stakeholder to communicate with each other to coordinate project deliverables, order supplies and monitor project progression.
- This will allow government representatives and customers to access all data from one place. When a government employee extracts an item of data for approval, it will be recorded through the blockchain ledger. The main role of the BIM manager, along with other management staff, is to use blockchain security systems to capture the organizational collaboration strategy.
- The main role of the BIM manager, along with other management staff, is to use blockchain security systems to capture the organizational collaboration strategy.

6-3 Outputs

- **The Design Stage:** Blockchain adoption shows more potential in the design phase, where the use of BIM is already at its highest. The combination of the two technologies provides tremendous value and can be considered as the appropriate direction for the effective development of the construction sector in the Arab region.

- **The Tendering Process:** Bids are evaluated and compared using programmed smart contracts, based on evaluation criteria determined by the customer.
- **The Construction Stage:** All stakeholder delivery requirements are traceable and visible, which improves supply chain workflow and ensures business integrity from start to finish. Once the project reaches the handover stage, all relevant stakeholder data will be validated, timestamped, and processed by the BIM manager through the blockchain exchange and stored in the cloud database.
- **The Maintenance Stage:** All information related to the maintenance activities of building systems are extracted from the blockchain. The collection of information related to the operation and maintenance of equipment makes it possible to monitor the regularity of the services provided by contractors.

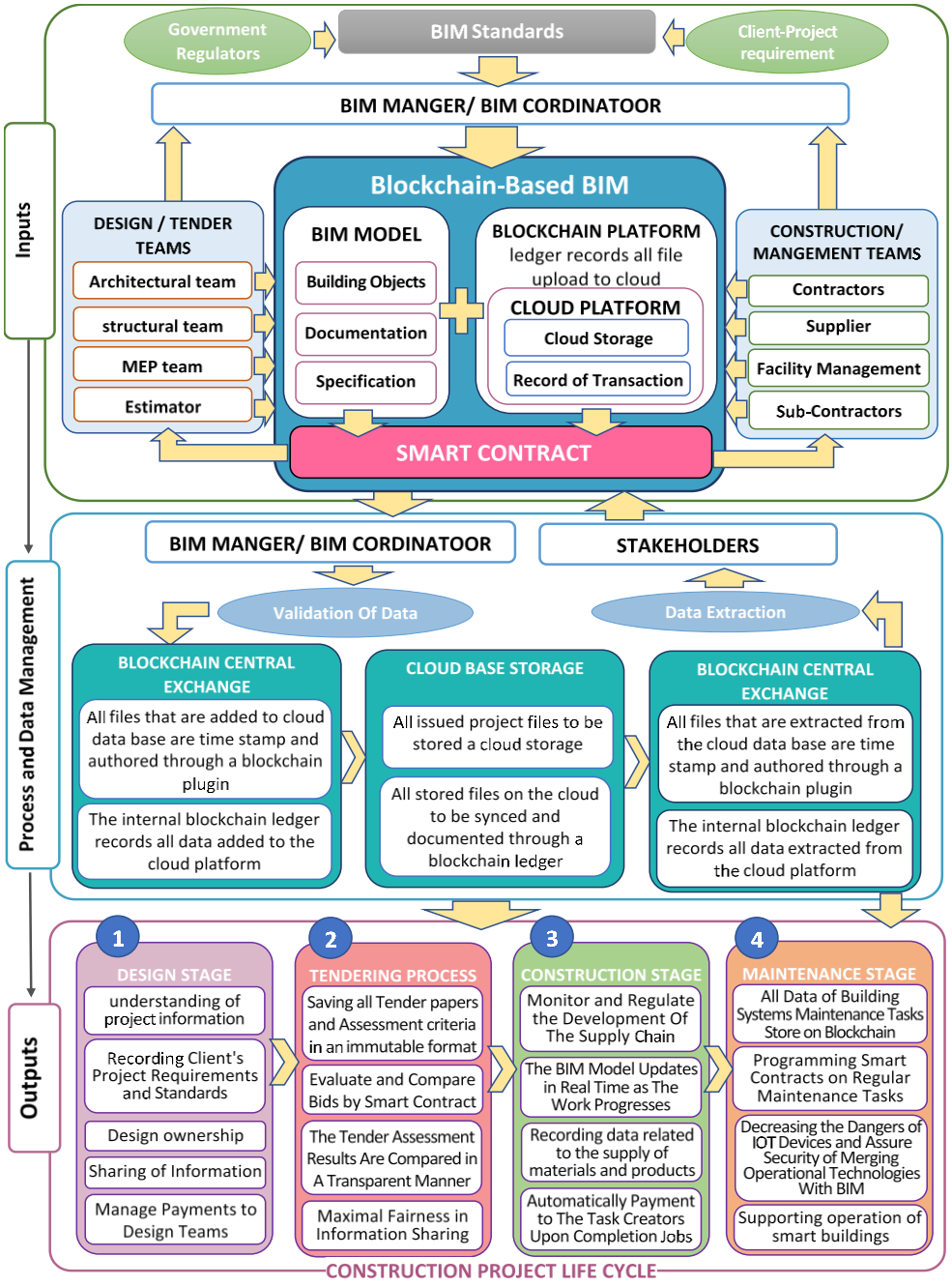

Fig. (12) A future conceptual framework for the integration of blockchain technology and BIM technology in construction industry in the Arab region [Author].

Findings and Recommendations

- Blockchain technology has recently received considerable attention from the construction industry, like many other industries. As a modern technology, it has strengths, offers great opportunities, involves some weaknesses, and possesses serious threats. Based on primary and secondary data from literature review and semi-structured interviews with experts, a SWOT analysis model was developed for the role of blockchain technology in shaping the future of the construction industry in the Arab region.
- The potential future advantages and opportunities from the integration of blockchain technology and building information modelling (BIM) technology in the construction industry in the Arab region were explored. The researchers also proposed a future conceptual framework resulting from the integration of the two technologies to facilitate automation of the design, construction, and maintenance of construction projects, This proposed framework is one of the most important main recommendations of this research.
- This research has shown that blockchain cannot be fully leveraged in the construction industry in Arab region without necessary adaptations and transformations in business models, procurement arrangements, and upskilling the construction industry. These stepwise changes are necessary for reaching a plateau of productivity in successfully importing blockchain in project life-cycle. To realize the true benefit of this developing technology for the Arab construction industry, beyond the hype, good-will, skepticism, and excitement currently surrounding it.
- It has been determined that the benefits of blockchain technology can theoretically be a solution to some problems faced by the construction industry in Arab region. However, research is still limited and several challenges remain for implementation. In particular, case studies of use cases in construction are lacking. In addition, the cooperation of the internet of things (IoT) with blockchain technology should be examined in more detail. As a result, blockchain technology is still fairly new to the construction industry.
- More research is needed to better understand the specific roles and responsibilities of stakeholders (such as governments, policymakers, customers, large and small organizations, suppliers, and end-users) to overcome the identified threats and weaknesses of the technology and to improve the construction industry in the Arab region and make it more efficient, higher in quality, and more trustworthy thanks to the many advantages of blockchain technology, such as privacy, trust, collaboration, and transparency. Automation, through blockchain technology-based BIM and integrated with a smart contract whose terms can be automatically executed, provides a comprehensive platform for the effective management of entire construction projects.
- this study shows that just academic and sectoral research alone is insufficient for the adoption of blockchain technology in the construction industry in the Arab region, in particular, blockchain technology should be better promoted to professionals in the construction industry and supported by pilot projects or case studies where those potential users can compare.
- Considering the anti-innovation nature of the construction industry, the sudden adoption of blockchain technology is not expected, the adaptation of Blockchain technology to the construction industry in Arab region will take several years. However, this is not a situation that necessitates ignoring the potential of blockchain technology in the construction industry. It is thought that companies that will use blockchain technology will gain a serious competitive advantage in the coming years.

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تقنية البلوكتشين ومستقبل صناعة البناء في المنطقة العربية: التطبيقات والتحديات والفرص المستقبلية

الملخص:

يعتبر قطاع صناعة البناء من أقدم القطاعات في العالم وله دور كبير في تنمية المجتمعات والنهوض بها، ومع ذلك تعاني صناعة البناء من إنخفاض إنتاجها وكفاءتها مقارنة بالقطاعات الأخرى نتيجة لعدة أسباب، منها المصالح المختلفة للجهات المشاركة بالمشروع وتخوف البعض من مواكبة التطورات التكنولوجية الحديثة، بالإضافة لانعدام الثقة بين المشاركين في المشروع والذي يعد من أحد أهم العوامل التي تقلل الكفاءة والإنتاجية. وقد ظهرت مؤخراً في عام 2008 م تقنية حديثة لديها القدرة على التغلب على الكثير من هذه التحديات التي تواجها صناعة البناء، هي تقنية البلوكتشين Blockchain والتى كانت وراء عملة البيتكوين Bitcoin المشفرة الشهيرة، وكان الغرض الرئيسي منها هو منع إجراء التغييرات على المستندات الرقمية والمحافظة على البيانات المخزنة بها والحيلولة دون تعديلها، وحالياً لها العديد من التطبيقات في العديد من المجالات على مستوى العالم، ويعاني قطاع البناء وبشكل خاص بالمنطقة العربية من قلة عدد الخبراء بإمكانات هذه التقنية وقدرتها على مساعدة صناعة البناء في العصر الرقمي، لذلك فإن الهدف الرئيسي من هذه الدراسة هو استكشاف دور تقنية البلوكتشين في صياغة مستقبل صناعة البناء والتشييد بالمنطقة العربية، وما يمكن أن تساهم به هذه التقنية وتضيفه إلى قطاع البناء وخاصة عند دمجها مع تقنية نمذجة معلومات البناء BIM، حيث يفترض الباحث أن إعتماد تقنية البلوكتشين في صناعة البناء والتشيد بالمنطقة العربية سيكون حلاً لجزء كبير من المشاكل الحالية بها التي أدت إلى إبطاء إعتماد تقنية نمذجة معلومات البناء. أعتمدت الدراسة على المنهج الوصفي التحليلي في مراجعة الأدبيات للتعرف على مفهوم تقنية البلوكتشين وتطبيقاتها في صناعة البناء ، ومنهج البحث النوعي باستخدام المقابلات العميقة شبه المنظمة مع الخبراء وذوي الإختصاص لجمع المزيد من المعلومات والبيانات الكيفية عن تقنية البلوكتشين وفوائدها وتحدياتها والفرص المستقبلية لها في صناعة البناء، وذلك بهدف إجراء التحليل الرباعي SWOT (نقاط القوة – نقاط الضعف – الفرص- المخاطر). كما تم استكشاف آراء وتجارب الخبراء تجاه المميزات والفرص المستقبلية المحتملة من تكامل تقنية البلوكتشين وتقنية نمذجة معلومات البناء في صناعة البناء والتشييد بالمنطقة العربية، للوصول الى اقتراح إطار عمل مستقبلي ناتج عن دمج التقنيتين لتسهيل أتمتة عمليات ومراحل التصميم والتنفيذ والإدارة الفعالة لكامل دورة حياة مشروعات البناء.

الكلمات الدالة : تقنية البلوكتشين - تقنية نمذجة معلومات البناء - تحليل نقاط القوة والضعف والفرص والتهديدات (SWOT).