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Original Article

Integrating Blockchain and BIM (BCT-BIM) to Promote the Construction Practices in Terms of Efficiency and Transparency

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Abstract *- Inefficiency, opaqueness, and dispute are the evils that cling to the body of construction. Blockchain, combined with BIM, can be an alternative to these issues. Trustable and Transparent: BCT ensures authenticity and transparency against records that cannot be repudiated as the fact records are available for decentralization on BCT, immune to third-party tampering; with the opportunity of Building Information Modelling (BIM) data-driven project execution efficiency improvement, such as data-rich collaborative environment that is being support in pre-checked information' relevancy and feasibility based on (BIM). This study examines the potential of BCT and BIM, separately (BCT-BIM), in improving efficiency and transparency in the overall construction facilities' lifecycle. A field survey was conducted in order to explore the most significant factors that were contributing to such integration. The findings reveal that the soundness of (BCT-BIM) integration is contingent on digital infrastructure, data security within organizations, and between actors. Furthermore, strategic planning, technological adoption, continuous workforce development, and effective stakeholder communication are key drivers of improving the construction sector's efficiency. In context, transparency can be increased through the adoption of (BCT), open communication, and contract clarity. The researchers propose a prototype model to illustrate the automation of smart contracts linked to (BIM) milestones, which significantly improves payment accuracy and transaction transparency, subsequently developing efficiency and transparency in the construction production processes. This study confirms that (BCT-BIM) integration has the potential to improve construction practices in terms of being more transparent, efficient, and reliable project delivery.*

Keywords *- Construction Industry, Blockchain Technology (BCT), Building Information Modeling (BIM), IoT Systems.*

1. Introduction

The construction industry plays a vital role in the global economy, as it provides essential infrastructure for growth and prosperity. Due to its complex and heterogeneous characteristics, it has long been regarded as facing the perennial problem of safety and transparency during operation, as well as issues such as ineffectiveness, high costs in the budgeting process, low quality control, or a non-quality management process. An example of such problems to solve is the unsettling, evident disagreement between stakeholders with a common purpose on the same project. Such problems arise from typical legacy approaches and existing production practices and systems. Construction developers are increasingly seeking to adopt modern technologies to overcome these challenges and improve operational and production processes. Modern technology offers promising avenues for addressing these obstacles and challenges. Building Information Modeling (BIM) has been at the forefront of these technologies for nearly two decades and is now relied upon to enhance the efficiency of construction production processes, with the aim of reducing the disputes and disagreements that have become almost an inherent characteristic of this industry [1]. However, as is well known, the role of this technology is limited to enhancing the design efficiency of the project by reducing conflicts, studying functional alternatives, and thus improving the project's functional and operational quality, and so on. But the problem of cash flow and financial dues to contractors remains one of the most prominent drivers of disputes and conflicts during the implementation phase, and the subsequent repercussions on the delivery period, final cost, and quality of services. In other words, Building Information Modeling (BIM) technology has solved a significant part of the main problem, but not the whole problem. This means that the construction industry still

needs to adopt more efficient methods for managing cash flow [2]. Recently, technologies have emerged specifically for financial transactions that enhance the efficiency of financial transactions with high transparency. The most prominent of these technologies is blockchain, and its high reliability in archiving and storing financial data can be relied upon to solve the remaining part of the problem. In addition to a wide range of research and academic studies that have recently emerged regarding blockchain's potential, features, and application capability in the construction environment. In order to enhance the construction industry's efficiency, its processes' transparency, and reliability throughout the project lifecycle [3-5]. Researchers have examined various aspects of these technologies and their promising potential in overcoming some of the construction's obstacles. Some of the studies addressing the aspects mentioned earlier are presented in Table 1 below.

Table 1. Some of the previous studies in the same research area

Year	Study Title	Summary of Key findings/ contributions
2023	"Integrating BIM and Blockchain across construction lifecycle and supply chains."	✓ The study proposed a framework for integrating these two technologies into the overall project lifecycle. ✓ The findings demonstrated the potential to promote communication and collaboration in the execution environment, increase efficiency, track resources, and automate payments through smart contracts.
2023	"Developing a BIM Single Source of Truth Prototype Using Blockchain Technology"	✓ In this study, a prototype that links BIM with Blockchain was presented. ✓ The prototype can serve as a tool to create a "single source of truth and a reliable and unified source of information. ✓ This model enables the transparent and secure sharing of construction data among all partners.
2023	"A Review on Blockchain Operations in Construction Management"	✓ The study examines the roles of (BCT) in managing the execution operations. ✓ It indicates that the (BCT) could serve as a basis for documenting "who did what and when," ✓ (BCT) would help reduce conflicts, enhance transparency, and improve collaboration among the project's stakeholders.
2024	"Building Information Modeling (BIM), Blockchain, and LiDAR Applications in Construction Lifecycle: Bibliometric and Network Analysis"	✓ A comprehensive review analyzed the literature of Blockchain, BIM, and LiDAR. ✓ The researchers showed the increased interest in these integrations between 2014 and 2023. ✓ The study highlights a research gap in the interaction of all these technologies together.
2024	"Unlocking Blockchain in Construction: A Systematic Review of Applications and Barriers"	✓ A review of over 100 research studies on (BCT) adoption in the construction sector. ✓ The review identifies 23 topics across 8 application areas (contracts, supply chain, asset management, maintenance, environmental issues, etc.). ✓ The review also highlights how blockchain's advantages can improve construction project management.
2024	"BIM and blockchain integrated construction management: a review."	✓ A systematic review examines the (BCT-BIM) integration. ✓ The study identifies five key application areas, which are innovation management approaches for data, contract, asset, procurement, and sustainability. ✓ The researchers discuss the challenges hindering the adoption of this integration.
2024	"When BIM meets blockchain: a mixed-methods literature review."	✓ The study is a review of research from the BIM and blockchain consortium. ✓ It identifies five key project-level use cases: design, payment management, execution event management, data management, and support for other execution tools. ✓ It also discusses the managerial and technical opportunities and challenges.
2025	"Three Decades of Innovation: A Critical Bibliometric Analysis of BIM, HBIM, Digital Twins, and IoT in the AEC Industry"	✓ The study is a bibliometric analysis of more than 5,500 papers published between 1993 and 2024. ✓ The study revealed that "the use of BIM along with technologies such as Blockchain, digital twins, and IoT" is increasing. ✓ It is also demonstrated a shift in research towards (sustainability, interdisciplinary approaches, and the adoption of technology integration).

1.1. Novelty of the Proposed Approach

Based on executive experience in the construction field and review of relevant literature in the same scientific field, researchers observe a pressing need for an integrated system that efficiently manages construction processes. This paper explores the possibility of integrating two technologies, BCT and BIM, to develop a framework system based on the operational advantages of each to be employed in the construction environment. The researchers aim to establish an integrated framework that serves the construction project development process, starting from the initial design phase or the conceptual design, through studying functional alternatives and implementing all operational systems to identify and resolve conflicts before final design approval and commencement of construction activities. This framework also encompasses managing key administrative activities during the execution phase, where transparency prevails, beginning from the public documentation in front of authorized parties, tracking possibilities, and revealing the supply chains' paths, and the certificates of origins' accessibility. In addition to settling the crucial issues of the financial dues, the electronic control of the real-time payments ensures a smooth production process. The study's aim is to maximize construction processes' efficiency and transparency by minimizing conflicts and disputes, thereby adopting new procurement methodologies or at least updating the traditional construction delivery approaches. The researchers formulate the research's hypothesis as: *(*BCT-BIM) integration can serve as an effective tool to manage production processes in the construction industry.

2. Methodology

The research methodology adopted by the researchers is as follows:

1. Define the key features of both technologies, Blockchain Technology (BCT) and Building Information Modeling (BIM); mechanisms, characteristics, and potential for integration in the construction environments to enhance the construction production processes in terms of efficiency and transparency.
2. Conduct a field study to investigate experts' opinions through questionnaires. The field study surveys a sample of highly qualified experts in the construction industry, including consultants, contractors, construction and engineering project managers, site supervisors, and resident engineers, with a minimum of 50 responses to ensure sufficient statistical reliability. The survey's objectives were:
   - Evaluate the factors that improve the construction sector's efficiency and measure the impact of each.
   - Identify the essential factors that increase the transparency of construction's production processes and those that promote it. These will form the foundation for the work system proposed later in the study.
   - Study the potential of integrating these two technologies (BCT-BIM) and the planned integration's key success factors to develop the current production processes in the construction sector.
3. Finally, a prototype model illustrates the automation of smart contracts linked to BIM milestones, to serve as a tool for managing construction activities in a way that improves efficiency and increases transparency in the construction sector.

Figure 1 shows the methodology's flowchart.

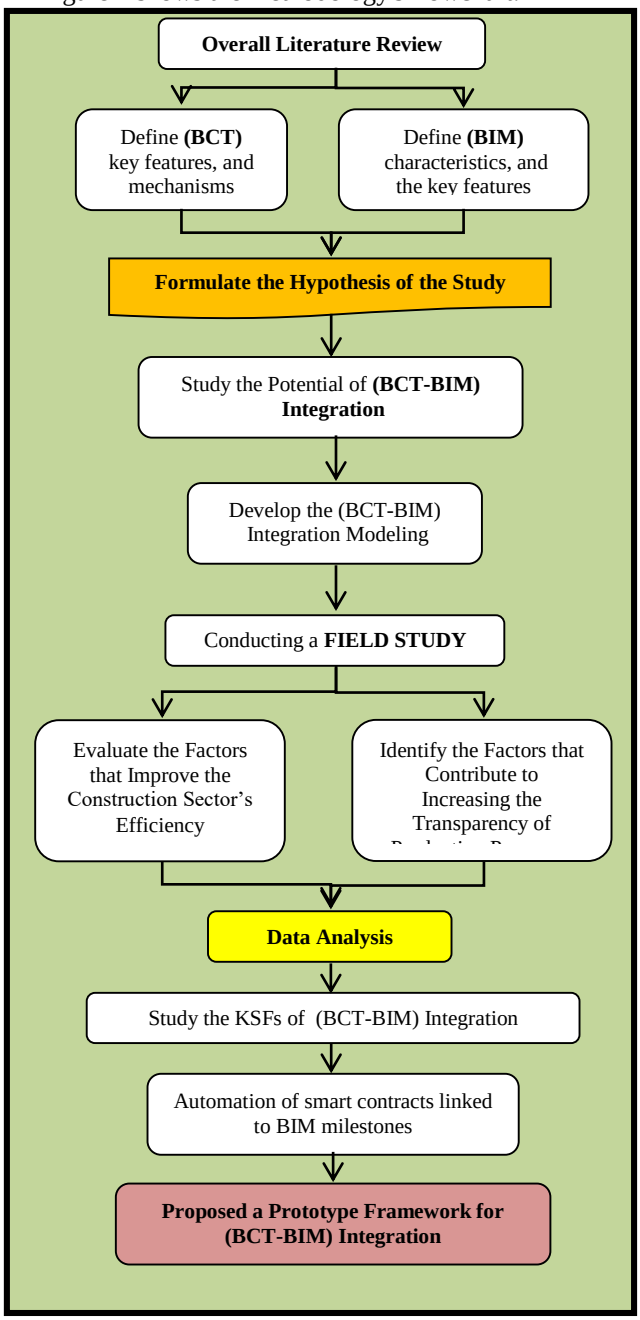

Fig. 1 Study's methodology

3. Blockchain Technology (BCT)

Blockchain Technology (BCT) is a distributed ledger system that enables recording transactions decentralized by all authorized parties to access the network. It is characterised by a highly secure and transparent encrypted form due to its unique encryption system. Where each transaction or data entry will create a block, and so on, each action will generate a new block linked to the previous and the subsequent one by a unique encrypted link to contribute to a chain of blocks, so it is called blockchain technology. This structure provides an immutable record where it is not permitted to modify or change the data without the consent of the entire network [6].

Formulated initially for cryptocurrency transactions, BCT has become a disruptive technology in several areas of business, as well as the construction industry. It has several features and is especially suitable to improve the efficiency and transparency in various industries, including (i) decentralization, (ii) transparency, (iii) immutability, and (iv) security [7]. Construction industry: BCT can handle the payment and facilitate procurement processes and supply chain logistics, as well as asset management [8]. By transparently recording transactions and project information, it can create trust among the involved parties and reduce fraud and dispute risks [9]. (BCT) can service the construction industry in several ways to address its challenges, such as Smart contracts, supply chain management, procurement systems, payment systems, and asset management.

The emergence of (BCT) and its advantages indicates that it can promote promising solutions to the construction industry's ongoing challenges, improve the efficiency of production processes, and increase the overall transparency of construction [6]. In general, (BCT) has broad abilities to promote the construction production processes. As well as creating a secure and immutable environment, its characteristics of change tracking indicate that blockchain's adoption in the construction industry can provide viable solutions to settle many challenges in this sector [10].

4. Building Information Modeling (BIM) Technology

"Building Information Modeling (BIM) is defined as a *digital modeling for a physical facility and its functional activities"*. It provides a platform to plan, construct, and manage the facility's activities for its overall lifecycle [11]. It involves creating and managing digital models that are rich in data, which can be used for planning, design, construction, and operation. (BIM) results in improved project efficiency, reduced errors, expedited project delivery, and enhanced asset performance and maintenance. Its adoption along the construction process improves cooperation and data exchange among actors [12]. Levation (BIM) has many advantages to enhance efficiency and increase transparency in the life cycle of construction projects [13], which are as follows :

1. Detailed and accurate modeling capabilities help identify and settle the potential conflicts early in the project's stages.
2. Facilitate the communications among partners by formulating a single, unified model that all of them can access and contribute to.
3. Reduced design errors by modeling building components and systems.
4. Efficient resource management by providing detailed information about materials, equipment, and labor requirements.
5. Provide a support platform during the overall lifecycle of the facilities, initially from developing conceptual design and detailed drawings to the stage of execution, and then to the operational and maintenance stages.

Integrating (BIM) into the construction industry has proven its value overall the project's lifecycle in terms of quality of execution plans and accuracy of the production processes' outputs by facilitating the execution processes. It is through creating a central platform for the data and information of the execution. (BIM) facilitates an optimal communication environment of sharing information among partners across all project stages [14].

5. Integration of (BCT-BIM) Technologies

The construction sector typically suffers from a lack of transparency, leading to ongoing disputes and, consequently, inefficiency. As mentioned above, it can provide an immutable record by (BCT) with a high level of transparency. Where all of the transactions and decisions will be saved and archived throughout the entire project's lifecycle [15]. From the researchers' point of view, this will enhance transparency, streamline processes, and improve trust among stakeholders. Whereas the process of controlling contracts is typically hands-on and time-consuming, with a number of opportunities for mistakes, procurement processes are often piecemeal and inefficient, resulting in bottlenecks that slow down business as well as increase overhead. Furthermore, construction supply chains are intricate, thus leading to counterfeiting and lead time problems [19]. This illustrates the need for (BCT) to enhance the traceability, confirm material authenticity, mitigate counterfeiting, and improve quality control [20, 21]. To this end, it is possible that (BCT), which can be connected with building information modeling, can solve the problems of traceable failure and lack of provenance in the history tracking on paper at the settlement stage. The purpose of the integration (BCT-BIM) is to merge the BCT technologies' data records, which are safe and stable, by using BIM's detailed, rich models. (BCT-BIM) Integration has had a great impact on the planning, operation, and management of buildings. It addresses those historical inefficiencies and lack of transparency." It also establishes trust based on partners, while at the same time avoiding disputes by streamlining practices and administration insane, hence fraud or data tampering-related risks. This includes promoting advanced

construction techniques, the development of green buildings, and pushing for good regulation. Finally, the quality of deliverables throughout their life cycle is improved [16]. This integration brings in the promise of much-improved efficiency and transparency to areas like project-wide management or quality control within the construction industry [14].

Integration of these two is likely to help enhance collaboration between the project's partners by establishing a secure, transparent, and integrated information exchange network for decision-making in the project. It also enables easy data sharing along the supply chain, which in turn promotes better coordination and eliminates choke points. Therefore, it can lead to shorter lead times, reduced costs, and overall supply chain efficiency improvements [15-18]. Overall, through the integration of (BCT-BIM), as described herein, the built environment can progressively transform towards a more agile, efficient, and sustainable future. It enables decision makers to make informed decisions, optimize resource deployment, and deliver high-quality projects that satisfy the demands of an ever-changing marketplace and regulatory regime.

The benefits of including (BCT-BIM) in construction production are vast; however, there is a lot yet to be developed in order for BCT-BIM to conform to its implementation. These challenges may hinder (BCT-BIM) integration [17]. The embedding into existing BIM software and systems would require extensive (BCT) knowledge, and testing of compatibility would also expose technical issues. The legal and regulatory structures for BCT may be murky or (at least at the time of this draft) insufficient, creating legal and compliance hurdles for companies that wish to embrace this technology. These challenges need to be addressed by all participants in the construction sector, including regulators and technology providers.

The benchmarking of the industry, facilitation of innovation, and supporting research and development are critical steps to remove barriers for implementation [33]. From the foregoing, the context o (BIM) technology becomes clear. It creates a digital work environment rich in information and detailed, accurate visual models of the functional form of each part of the planned structure. This constitutes a highly flexible collaborative environment for managing the shared or conflicting interests of stakeholders in a single project [34]. However, BIM models lack the ability to track and manage the implementation of activities and processe. They are effectively used as a planning aid that produces effective plans for the execution of the project. They can also serve as standard documents for authorized technical information and data in settling disputes and disagreements occurring on and following the initiation of the project work. But they do not care what will happen to the real implementation actions that translate these plans from paper-and-ink into incarnated things existing in reality [35]. It should also be noted that although BIM models are both flexible and able to contain alterations to the information relating to the structure, they cannot be entirely immune from tampering and must still be checked or validated before being adopted for use. This emphasizes the rationale of our study, where we aim to combine two technologies that can function in synchrony digitally as a holistic management tool. This is achieved by addressing weaknesses or flaws in digital models in (BIM) with digital blocks in blockchain technology [36].

It generates network-stored digital models, which can be updated and validated in real time to see whether modifications would simply be impossible. These are tagged inspections and work in essentially a similar manner to checkpoints in the roadbuilding process: construction processes are brought up to a set of requirements and tested for compliance. Consequently, payments to contractors are phased according to these requirements. In addition, tamper-proof records are archived showing each step of the building process, from raw materials selection and transfer from origin up to final installation, including testing and certification. Therefore, the proposed integrated environment (BCT-BIM) can serve as an effective management tool, improving the efficiency of the production processes and minimizing the often-weak transparency in the construction sector. This lack of transparency is a primary driver of many disputes and conflicts among parties involved in the construction process..

6. Field Study and Data Analysis

The researchers assigned a highly qualified, selective sample of experts in the construction sector, including consultants, contractors, construction and engineering managers, site supervisors, and resident engineers, all of whom possess substantial professional experience across various types of construction production processes, in order to investigate the study's data and information.

A questionnaire form was designed by the researchers to collect data. The form investigated the factors relied upon to improve efficiency and increase transparency of production processes in the construction industry, as reviewed in the relevant literature [24-32]. The questionnaire consisted of three main axes:

- Asking the expert to evaluate the factors of improving construction practices' efficiency according to their degree of importance and influence.
- Asking the expert to evaluate the factors of increased transparency of the construction processes, as to the degree of importance and influence.
- Their recommendations and suggestions for the key successful factors of the (BCT-BIM) integration.

Figures 2 and 3 show images for the questionnaire forms used to collect the study's data.

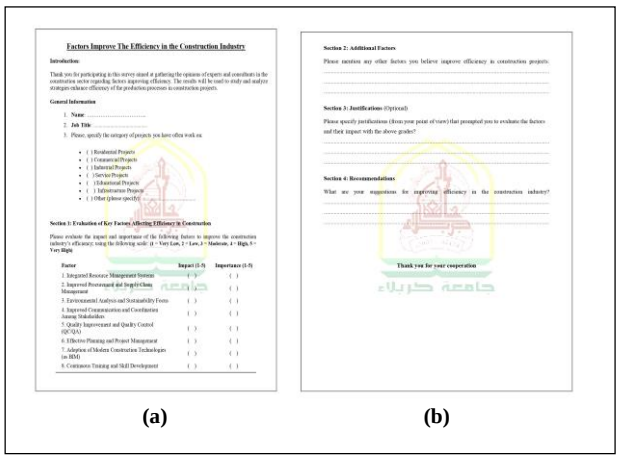

Fig. 2 Questionnaire form No. 1

6.1. Background of Survey Participants

The researchers were generally keen to achieve a sample size of at least 50 answers to achieve a sufficient degree of statistical reliability. The sample size surveyed was 59. The level of education and types of jobs factor was adopted as a basic factor to show the best results through the participants' answers to the questionnaire, the questions of which are shown. Figures 4 and 5 below show the experience of the participants in the questionnaire in the construction industry.

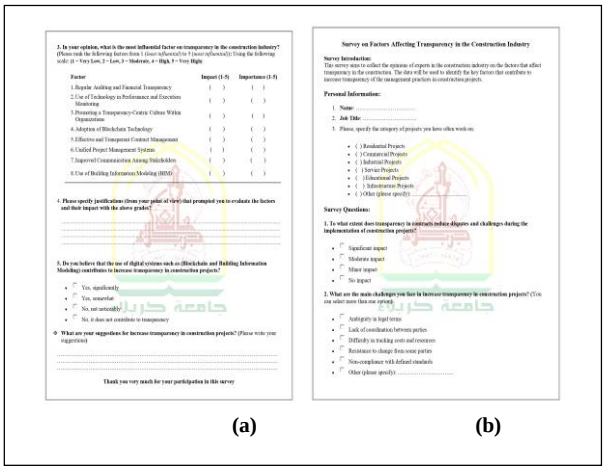

Fig. 3 Questionnaire form No. 2

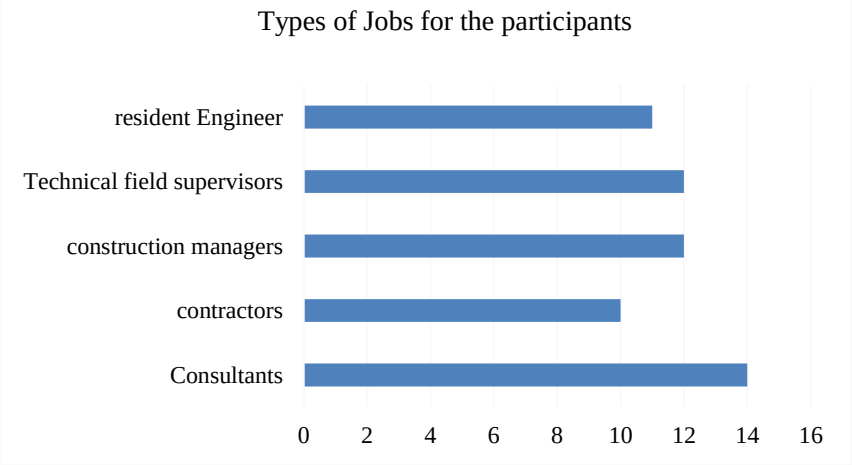

Fig. 4 Shows the participants' jobs

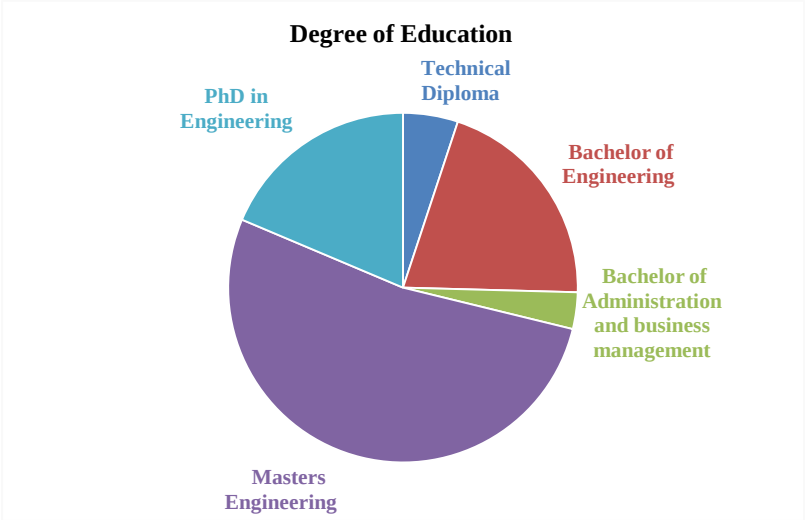

Fig. 5 Shows the level of education

Tables 2 and 3 show the ranking of the influencing factors according to their importance and degree of influence, as determined by this study. The answers derived from the study were subjected to reliability and validity tests to verify the extent to which the targeted requirements for completing this study were met. The collected answers reflected a good degree of consistency by repeating them to achieve the best possible measurement of the measured value by adopting the (Cronbach's Alpha) test. Values of both reliability and validity were within limits higher than the threshold limit for accepting the results, which is 0.7. The values of reliability and validity were good at about 0.78. The key factors for successful integration of (BCT-BIM) are listed based on experts' opinion as below.

Table 2. Ranking factors of improving efficiency by degree of importance and impact

No.	Factors	Average Impact Rating	Average Importance Rating	Impact Level	Most Prominent Justifications from the Experts' Point of View
1	Effective Planning	5	5	Very High	Proper planning has a significant impact on reducing delays and cost overruns.
2	Adoption of Modern Construction Technologies (as BIM)	5	4.3	Very High	Modern technologies reduce errors, speed up processes, and increase overall efficiency.
3	Continuous Training and Skill Development	4.7	4.3	High	Proper training enhances team effectiveness and reduces errors.
4	Integrated Resource Management Systems	4.5	3.9	High	Optimizing resource use significantly reduces costs and increases productivity.
5	Improved Commun. and Coordination Among Stakeholders	4	3.7	Moderate to High	Effective communication improves project speed and reduces mistakes
6	Improved Procurement and Supply Chain	3.64	3.5	Moderate	Enhancing the supply chain improves cost-efficiency and speeds up workflows.
7	Environmental Analysis and Sustainability Focus	3.5	3.4	Moderate	Sustainability contributes to long-term cost reduction and increases efficiency in projects.
8	Quality Improvement and Quality Control (QC/QA)	4	3.2	Moderate	Maintaining high quality reduces additional costs and improves efficiency

Table 3. Ranking the factors of increasing transparency by degree of impact and importance

No.	Factors	Average Impact Rating	Average Importance Rating	Impact Level	Most Prominent Justifications from the Experts' Point of View
1	Adoption of Blockchain Technology	4.8	5	Very High	Blockchain provides a robust tool for enhancing transparency and reducing fraud.
2	Improved Commun. Among Stakeholders	5	4.77	Very High	Open and continuous communication is essential to ensuring transparency in all project processes.
3	Effective and Transparent Contract Management	3.88	4.1	High	Transparent contract management helps eliminate ambiguity and ensure clarity.
4	Unified Project Management Systems	4.15	3.79	Medium to High	Integrated systems make it easier to access information and improve transparency.
5	Use of Building Information Modeling (BIM)	5	3	Moderate	BIM technologies help facilitate collaboration and transparency in processes
6	Regular Auditing and Financial Transparency	3.8	3.6	Moderate	Regular auditing enhances financial transparency and helps identify any suspicious activities early.
7	Promoting a Transparency-Centric Culture Within Organizations	3	4	Moderate	Promoting transparency within organizations helps build a fair and ethical working environment.
8	Use of Technology in Performance and Execution Monitoring	2.45	3.5	Moderate	Modern technology contributes to monitoring project progress and enhancing transparency.

The field study revealed several key factors that can promote the efficiency improvement of construction production processes. The most important of these is adopting effective planning methods through the implementation of modern technologies such as BIM. These two aspects received the highest ratings from experts, indicating their paramount importance compared to the other factors studied. Meanwhile, the field study results highlighted major weaknesses in transparency, which directly impact the volume of disputes and conflicts in the construction sector. The findings pointed to the critical need to enhance transparency practices in the construction contracts, particularly traditional ones (it should be noted that the researchers will dedicate a separate field study to investigate traditional construction contracts' weaknesses). Furthermore, the study emphasizes the need to reorganize financial transaction procedures and real-time payments due to contractors. The use of digital representation and electronic archiving, accessible to all parties and the project's stakeholders, enhances transparency and trust in dealings and exchanges among all partnerships involved in the project. This answers the study's hypothesis. The experts' opinions expressed in the field study directly conclude that the construction sector has a pressing and real need to adopt modern technologies for archiving all movements and details

of production processes. This begins from the project's design phase, including the establishment of building specifications in contracts and agreed-upon payment agreements, and continues overall the execution phase, encompassing transparent and efficient supply chain management, inspection documentation, in addition to the creation of "as-built" drawings. It also includes managing maintenance records during the operational and functional service phase. The experts clearly point to a technology like Blockchain Technology (BCT) that can meet the construction's transparency requirements. This is the main aim of this study: to highlight that integrating the features of both technologies into a (BCT-BIM) integration will create a highly data-rich and transparent environment of detailed digital building models. In addition, compatibility will be supported with all routines and systems accurately, as well as their smooth implementation and operation without conflict. But it is the hole in (BIM) for tracking business transactions and contract processes during the execution phase of a project. The importance of incorporating BCT elements to improve the advanced models of management described in this paper is emphasized here. On the contrary, however, it has been found that the success of (BCT-BIM) integration depends on a multitude of factors. It is basically a matter of transparency and cooperation with everyone, and also retaining the sort of tech environment where we have strong cybersecurity. The most significant factors that resulted in the success of this integration are shown in Table 4, sorted based on their importance.

Table 4. Success factors of (BCT-BIM) integration

No.	Factors	Deception	Relative Importance
1	**Transparency and Reliability in Data Exchange**	Such features are the cornerstone for successful integration. Blockchain is a secure, transparent ledger of all transactions and data. If information for a project, such as contracts, payments, and design changes, can be brought in from BIM to Blockchain, then tracking that information and validating its integrity becomes easier.	Very High
2	**Collaboration Among Stakeholders**	Blockchain promotes collaboration between stakeholders by establishing a shared and trusted ledger, while BIM enhances coordination between teams by means of a virtual environment. This is invaluable for expediting decision-making and ensuring that everyone has the appropriate information in a timely manner.	High
3	**Technological Integration and Infrastructure**	Companies must also have certain technical infrastructure capabilities from a BIM viewpoint to connect Blockchain with BIM. That involves bringing systems up to date and giving the right environment, such as cloud storage for data.	High
4	**Cybersecurity and Data Protection**	As Blockchain operates based on encrypted security, the protection of data is fundamental. Guaranteeing the security of critical project data as well as securing against attacks increases the efficiency of integration.	Medium to High
5	**Training and Professional Development for Stakeholders**	Engineers, contractors, and project managers should all be taught how to use Blockchain & BIM in a technically efficient manner. This involves knowing how to join data, system management, and solving technical issues	Moderate

6	**Regulatory Compliance and Standards**	Some governments or regulatory bodies require adherence to legal standards when using technologies like Blockchain and BIM. Integrated solutions must comply with local and international regulations.	Moderate
7	**Change Management and Digital Transformation Capability**	The success of integration requires the ability to manage change within companies that rely on traditional methods. This includes leadership support and decision-making regarding digital transformation	Moderate
8	**Cost and Financial Availability**	Although the benefits of integrating Blockchain and BIM are significant, implementation costs, including software purchases, team training, and infrastructure updates, can be a barrier.	Medium to low

The researchers concentrated on the dimensions of success factors in the integration. The most crucial of these, say the experts questioned by the study, is abundant and accurate data to feed all aspects of the project's digital model, creating clear target times throughout its development. Such data is crucial for creating smart contracts that can automatically release financial entitlements once the model's conditions and requirements are met. An electronic framework for (BCT-BIM) integration is also an essential consideration. All this needs the same teamwork among all the players, and also a safe, encrypted transaction for tougher data security. Experts have also been directed to another crucial factor. Those are the rules and laws about how the project needs to be executed. Ultimately, it is the digital infrastructure and the financial resources that are necessary for the successful completion of the intended technical integration.

7. Prototype Framework for (BCT-BIM) Integration

In this study, a prototype for integrating blockchain technology with Building Information Modeling (BCT-BIM) integration oriented towards instant phase verification and payment processing is proposed in an effort to automate construction process progression and improve the transparency within the construction sector. Once detailed digital models of the final project layout, including specifications in enough detail for each scope of work, system operation and flow, and operational performance (during the project's life), are finalized, then automated milestones can be set. These deadlines trigger smart contracts to disburse payment once a phase is verified. These contracts (connected with the BCT platform) are imported. The above process can be summarized as follows:

1. Import the building's BIM model and define its phases by milestones.
2. Programming or developing the corresponding smart contracts for each of the milestones that are assigned in the above step
3. Update the status of each phase within the BIM model.
4. Activate the smart contract after verifying the phase's completion.
5. Once the smart contract verifies the phase, it executes the associated payment.
6. In case of verification failure, an alert is issued indicating the appropriate actions. Figure 4 illustrates the workflow diagram.

BIM model (e.g., Autodesk Revit or an IFC format) should include specific metadata for each milestone:
- *Milestone ID (Milestone_ID)*
- *Completion Date (Completion_Date)*
- *Status Indicator (e.g., Completed)*

Once the milestone status is set to 'Completed', a digital trigger is sent to the Blockchain, which prompts the smart contract to verify and subsequently release the appropriate payment if conditions are met. The researchers used artificial

intelligence to help develop a simplified model of a smart contract in Solidity. Language. Figure 6 below illustrates a sample of smart contract code. Based on the research findings, Figure 7 illustrates the main interconnection stages for the (BCT-BIM) integration process in terms of maximizing efficiency and transparency in the construction sector. (BCT-BIM) Integration can serve as a means that provides a decentralized record, facilitating real-time access to information by all project stakeholders without requiring prior authorization from one party or another, thus creating, from the researchers' point of view, a highly transparent working environment among the partners. Therefore, increase efficiency by improving the execution process, starting from selecting the contractor stage and organizing the contracts that are suitable to the nature of the work in question (smart contracts), then the stages of supplying, receiving, reviewing and auditing materials, and ensuring their conformity to the approved technical specifications and designs, passing through project's building and operating stage. They are the results that such employers hope for, and they can change perceptions in environments where "the gap' in terms of financial and administrative corruption is so wide it will never be narrowed by government-level intervention (such as some high-level work in developing countries)." The achievement of just these sorts of outcomes depends on extraordinary efforts to overcome, among other things, barriers to integration placed on agencies that have not integrated on an efficient enough basis with relevant authorities/administrations, be they governments/multinational corporations/or key CEOs, etc. The proposed idea is commendable and merits support for its success.

```
pragma solidity ^0.8.0;
contract PaymentForConstruction {
address public owner;
address public contractor;
uint public milestonePrice;
bool public milestoneCompleted;
constructor(address _contractor, uint _price) {
owner = msg.sender;
contractor = _contractor;
milestonePrice = _price;
milestoneCompleted = false;
}
function markCompleted() public {
require(msg.sender == owner, "Only the owner can confirm
completion.");
milestoneCompleted = true;
}
function releasePayment() public {
require(milestoneCompleted, "Milestone not yet
completed.");
payable(contractor).transfer(milestonePrice);
}
receive() external payable {}
}
```

Fig. 6 Sample of a preliminary smart contract code

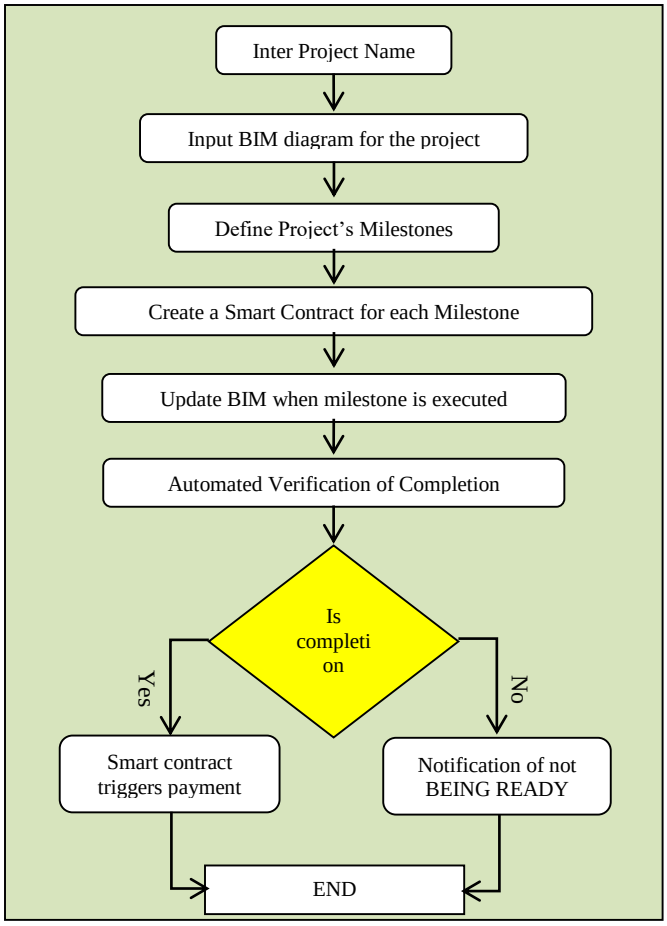

Fig. 7 Main interconnection stages for the (BCT-BIM) integration process

8. Conclusion

In the construction environment, there is an urgent need to address the challenges in the production processes. It is driven by the need to address persistent inefficiencies, fragmentation, dispute settlement, and the lack of transparency overall in the production cycle. This study demonstrates that (BCT-BIM) integration can provide a robust and innovative framework for overcoming these structural challenges. Through the integration of Building Information Modeling (BIM), a collaborative and data-rich modeling environment, and Blockchain Technology (BCT), a secure, immutable, and decentralized ledger system, construction processes can be reshaped for higher operational efficiency and more transparency amongst different stakeholders involved in the project. The field study concludes that enhancing construction industry production processes relies essentially on effective planning and promotes it as an enhanced production blueprint supported by the adoption of advanced digital tools, such as Building Information Modeling (BIM), integrated resource management, and continuous training for the workforce. Concomitantly, facilitating transparency is greatly driven by the adoption of (BCT) to trace transactions, open communication, and transparent contract management models.

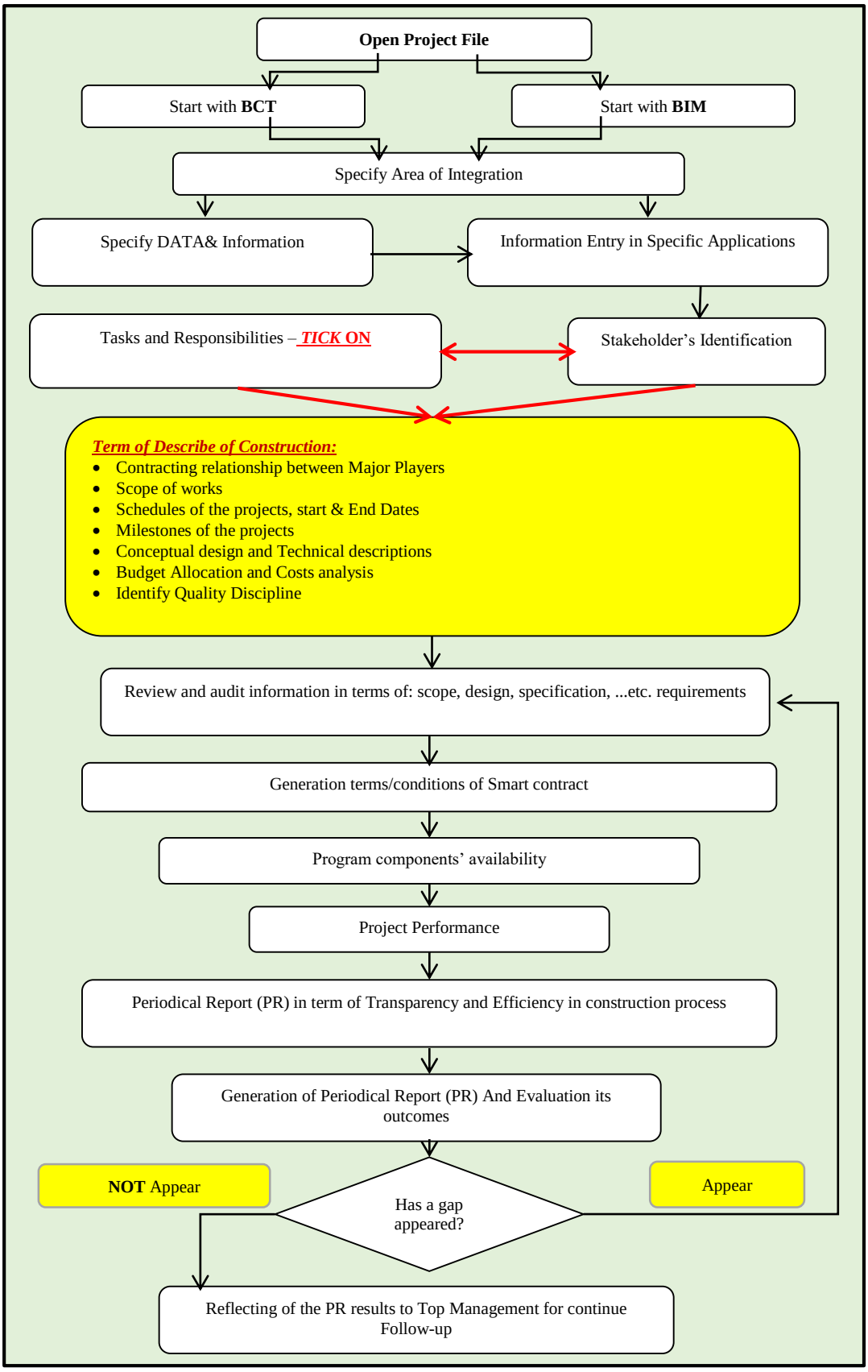

Fig. 8 Shows the outlook of the proposed (BCT -BIM) integration in terms of construction's efficiency and transparency

This work found eight key success factors for the use of (BCT-BIM) categorical data, the first one is technological infrastructure, and in this regard, cybersecurity in data exchange is very important. Transparency, collaboration, education, regulatory adherence, digital readiness, and financial support are also seen as important drivers. A prototype is designed to showcase the application of smart contracts in action with BIM-task defined milestones as illustrated in Figure 8. Results demonstrate a significant reduction in payment delays, disputes, and the requirement for manual oversight, underscoring the power of the integration to streamline efficiencies and delivery confidence. Now we can harness these cutting-edge technologies to produce a wide variety of construction delivery systems, including the traditional bid process. In conclusion, BCT-BIM integration acts as a game-changer for reforming construction industry practices and adopting global megatrends like sustainability, digitization, and responsibility. The success of such an implementation depends not only on technological advancement but also on the readiness of organizations, inter-organizational collaboration, and regulatory support.

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