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Review Article

Smart Contracts in the Construction Industry: A New Era of Transparency and Efficiency

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Abstract

Construction industry often faces challenges such as payment delays, contract disputes, and a lack of transparency and administrative efficiency. Smart contract technology based on blockchain offers an innovative approach to address these issues through transparent, automated, and tamper-resistant systems. This study explores various applications of blockchain and smart contracts in construction projects, including solutions for automated progress payments, digital contract management, quality improvement, and technology-based dispute resolution, using the Systematic Literature Review (SLR) method. Smart contract systems can execute payments automatically based on verified work progress, while blockchain technology ensures secure and immutable data recording. Additionally, integration with technologies such as Building Information Modeling (BIM) and the Internet of Things (IoT) enhances real-time project management. Despite offering numerous benefits, the implementation of these technologies still faces challenges such as regulatory uncertainty, infrastructure readiness, and the need for standardization. This study highlights that the adoption of blockchain and smart contracts holds significant potential to drive efficiency, fairness, and digital transformation in the construction sector.

Keywords: *Blockchain, Construction, Dispute, Smart Contract, Technology.*

1. INTRODUCTION

The global construction industry currently faces various structural challenges, including payment delays, administrative uncertainties, weak transparency in the supply chain, and a high incidence of disputes among project stakeholders. These issues result in significant inefficiencies, reduce trust among parties, and can even lead to project failure [1]. The emergence of digital technologies such as blockchain and smart contracts offers new solutions that have the potential to transform how these problems are addressed. Blockchain enables transparent, immutable, and verifiable data recording across multiple parties, while smart contracts allow for the automatic execution of agreements based on pre-programmed conditions [2].

One of the primary issues frequently encountered in the construction industry is payment delay, wherein the contractual rights of parties, especially contractors and subcontractors, are often paid after the agreed deadline, or in some cases, entirely neglected. This situation is often triggered by unresolved disputes, disagreements over work progress evaluations, or weak verification and reporting mechanisms [3]. Such conditions not only disrupt cash flow and financial stability for project implementers but can also create a domino effect leading to project delays, inter-party conflicts, and even the risk of bankruptcy.

On the other hand, contract administration processes in construction projects are complex and heavily reliant on manually generated documents that require significant human intervention [3]. This complexity increases the likelihood of administrative errors such as inaccurate data input, miscommunication, or misinterpretation of contract terms. These mistakes can directly impact project success in terms of completion time, work quality, and overall cost. Hence, there is a growing need for a system that enhances transparency, accelerates validation processes, and reduces dependence on

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manual procedures in managing contracts and project payments.

In the construction context, several studies have proposed smart contract-based systems to ensure progress payment security, such as the Smart Contract System for Security of Payment in Construction Contracts (SMTSEC) [1], Blockchain-Based Smart Contracts (BBSC) [4], and BIMcontracts [5]. These studies demonstrated the effectiveness of such technologies in addressing payment delays, improving contract management efficiency, and reducing conflicts through data automation and transparency.

Nevertheless, the adoption of this technology faces several challenges, including the lack of a legal framework [6], and organizational resistance or unpreparedness for change [3]. In developing countries, the readiness for implementing smart contract technology remains low due to limited infrastructure and human resource capabilities. Therefore, this Systematic Literature Review aims to analyze various approaches, findings, and benefits of smart contract implementation in the construction industry.

2. METHOD

In this study, a Systematic Literature Review (SLR) approach is employed to conduct an in-depth examination of existing literature related to the application of blockchain technology and smart contracts in the construction industry. The SLR methodology provides a structured and replicable process for identifying, evaluating, and synthesizing relevant academic works, allowing for a comprehensive understanding of the state of research in this field [7].

The data collection phase involved a rigorous search for scholarly literature from reputable academic databases, particularly those indexed by Scopus, to ensure the inclusion of high-quality and peer-reviewed sources. The search was conducted using a set of carefully selected keywords that were both relevant and specific to the research topic, such as: blockchain, construction, dispute, smart contract, and technology.

To maintain a high standard of relevance and validity, inclusion and exclusion criteria were established prior to the literature screening process. These criteria considered factors such as publication year, source credibility, language, the presence of empirical data or case studies, and the extent to which the article addressed the core themes of blockchain and smart contract implementation in construction projects. Duplicates and articles that did not directly relate to the research objectives were systematically removed.

Following the selection phase, the eligible literature was subjected to a qualitative analysis, aimed at identifying the various technological approaches proposed or implemented in the construction sector. This analysis also focused on extracting key findings concerning the benefits of blockchain and smart contract technology, particularly in terms of improving transparency, automation, and payment efficiency, as well as exploring the challenges and limitations associated with their adoption, including legal, technical, and organizational barriers.

By synthesizing the insights from multiple studies, this SLR provides a comprehensive and evidence-based overview of the current landscape, trends, and research gaps in the implementation of smart contracts and blockchain within construction project environments. The systematic methodology ensures that the conclusions drawn are grounded in existing academic knowledge and offer valuable implications for both researchers and industry practitioners. The detailed steps of the literature search and selection process are illustrated in Table 1.

Table 1. Literature research processes

No.	Component	Description
1	Keyword	Blockchain, Construction, Dispute, Smart Contract, and Technology.
2	Domain	Scopus Q1-Q4
3	Year of Publication	2020-2025 (last 5 years)
4	Boelan	"AND" is used to narrow the search to match the specific research topic

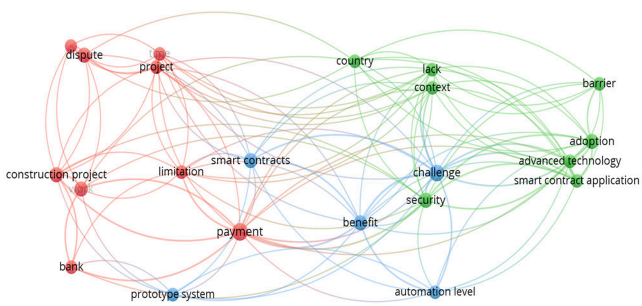

Figure 1. Diagram visualization using VOSviewer

Subsequently, keyword modelling was conducted using the VOSviewer application, as illustrated in Figure 1, to map the existing body of research related to the topic. VOSviewer is a widely used tool for constructing and visualizing bibliometric networks, allowing researchers to identify clusters of related terms, co-occurrence of keywords, and thematic trends within the selected literature [8].

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This keyword mapping process served to provide a visual representation of the research landscape, highlighting the most frequently appearing terms and their interconnections, thereby offering insights into dominant themes, emerging areas, and potential research gaps. The visualized network enabled a more structured understanding of how studies on blockchain and smart contracts in the construction industry have evolved over time.

Following the visualization, the identified keywords and clusters were filtered and refined to ensure alignment with the specific focus of this study. Only those nodes and linkages that were directly relevant to the research objectives were retained for further analysis. This step was crucial in enhancing the validity and specificity of the literature review by narrowing the scope to studies that contribute meaningful insights into the application of smart contracts in construction.

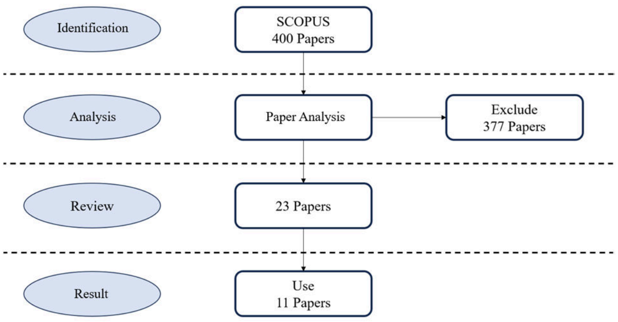

Figure 2. SLR process diagram

A total of 400 articles were initially collected. In the subsequent analysis phase, a preliminary review of all articles was conducted to assess their alignment with the research criteria. Based on this review, 377 articles were excluded for not meeting the predetermined criteria, leaving 23 articles for further examination. The next phase involved a more in-depth review, during which the 23 remaining articles were evaluated for relevance and content quality. Following this process, only 11 articles were deemed suitable and were ultimately used as the foundation for the research findings.

For a paper that uses mathematical modeling, the method may contain model approaches, model justification, algorithms for solving models, and techniques.

The method should contain experimental materials, tools, and procedures for an experimental research paper.

3. RESULTS AND DISCUSSION

The development of digital technology has opened up significant opportunities for the transformation of the construction industry, which has long been known for its complex processes, complicated documentation, and vulnerability to disputes. One of the most promising breakthroughs in the last decade is the use of blockchain and smart contracts. These two technologies offer a new approach that is more efficient, transparent, and secure in project management. Various studies have shown that the application of these technologies is not merely conceptual but has begun to be implemented in real-world systems and prototypes.

In this context, a smart contract is defined as a digital transaction protocol that can automatically write, verify, and enforce the terms of a contract, typically built on blockchain technology. In the construction industry, smart contracts are believed to address classic issues such as contract disputes, payment delays, as well as problems of transparency and accountability in the supply [9]. Additionally, smart contracts have the potential to support the integration of other technologies such as BIM (Building Information Modeling), IoT (Internet of Things), robotics, and artificial intelligence (AI).

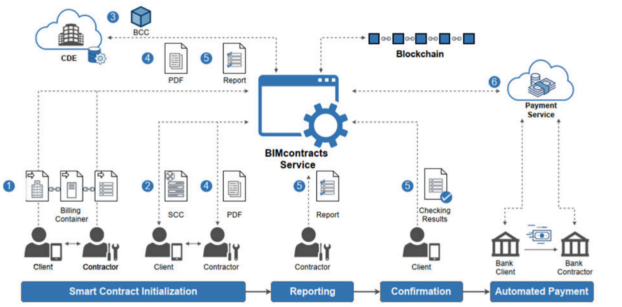

Figure 3. Smart contract illustration [5]

Automation in Project Payment

Payment delays represent a critical and persistent challenge in construction projects, with direct implications for cash flow management, contractor business continuity, and the potential escalation of disputes among stakeholders. In response to this issue, a number of scholarly investigations have proposed smart contract-based systems designed to automate payment processes and enhance procedural efficiency.

SMTSEC, short for Smart Contract System for Security of Payment of Construction Contracts, utilizes Ethereum blockchain and smart contracts to manage construction project payments in an automatic, secure, and transparent manner. Its goal is to ensure that all parties involved such as main contractors and subcontractors receive their payments on time, without going through lengthy administrative procedures or relying on third parties like banks. At the start of each month, the client approves the planned payment amount and locks the corresponding funds in Ethereum (ETH) for that

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payment period. This ensures that the funds are available before the work begins. Once the work is completed and progress is approved, the system automatically transfers funds to the digital wallets of the main and subcontractors according to the agreed terms. This process is executed through smart contracts with no manual intervention required.

BBSC (Blockchain-Based Smart Contract) offers a similar approach, adding features like fund freezing and progressive disbursement [4]. Unlike SMTSEC, BBSC is integrated with banks and uses digital tokens that represent fiat currency. Once work is verified by a Quantity Surveyor (QS) or inspector, the smart contract releases the funds automatically via a system linked to the bank. BBSC consists of three main phases: (1) smart contract initialization and configuration, (2) payment freezing, and (3) disbursement application. The payment cycle involves early fund freezing based on projected work value and automatic disbursement once contractual conditions are met. Web and mobile applications are used to input data from stakeholders, while the smart contract algorithm verifies payment conditions before validating transactions on the blockchain. The automation of construction payments through blockchain and smart contracts offers a viable and transformative solution to longstanding inefficiencies. Blockchain ensures immutable, transparent, and real-time recording of transactions and work progress, accessible to all stakeholders across the supply chain. This transparency mitigates the risk of data manipulation and dispute occurrence. Smart contracts further streamline the process by executing payments automatically based on the completion of predefined project milestones. For instance, upon digital verification (via systems such as BIM or inspection reports) that 30% of the construction scope has been fulfilled, the smart contract automatically makes payments based on the agreed shares, removing the need for manual steps like sending invoices or getting approvals.

Blockchain-based payment systems yield levels of security and transparency unattainable by traditional methods. Owing to the decentralized nature of blockchain, no single actor can unilaterally alter transaction records for personal gain. Moreover, smart contracts can be programmed to proportionally allocate payments among stakeholders. For example, 60% to the main contractor, 30% to subcontractors, and 10% to suppliers in a single, automated blockchain transaction.

Each transaction is recorded on a public or permissioned blockchain, enabling all relevant parties to independently verify payment flows without relying on intermediaries or manual administration. This minimizes the potential for fund misappropriation, strengthens project cash flow stability, and supports continuity across the construction supply chain. Nevertheless, the successful deployment of such systems necessitates the development of standardized digital contract frameworks, integration with existing project reporting systems (e.g., BIM or ERP), and the establishment of a robust legal infrastructure that formally recognizes the enforceability of blockchain-based smart contracts.

One notable real-world implementation of a smart contract-based payment system is the SMTSEC, which was tested in a construction project involving a 3,000 m² powerhouse building in Turkey, with a contract value of USD 20 million [1]. In this case, the SMTSEC system was deployed as a parallel platform to the traditional payment process. It successfully automated monthly progress payments by locking the projected payment amount in Ethereum (ETH) at the start of each month. Upon employer approval of completed work, the system instantly transferred funds to the digital wallets of the main contractor and two subcontractors while one responsible for reinforcement works and the other for concrete structure. The payment process took only seconds on the Ethereum test network, and all transactions were executed without manual intervention or delays. Moreover, structured interviews with project participants revealed unanimous agreement that the system effectively reduced payment-related risks, improved transparency, and increased confidence in financial flows across all parties.

Contract Management

In contract management, a conceptual model called the Tri-Dimensional iContract (TDiC) is used, which includes three main dimensions: systems and processes, organizational behavior, and environmental factors [3].

In the systems and processes, iContract helps to improve contract management by enabling real-time scenario analysis, automating administrative tasks, increasing supply chain efficiency, and supporting fairer, performance-based payments. The iContract system can digitally create contracts based on user inputs such as project type, contract value, duration, and risks. It can also recommend relevant clauses from a contract database based on the project's conditions. This reduces the time and cost of negotiation and avoids ambiguity in agreements.

Construction stakeholders need to begin adapting to digital working methods and be more open to using automated technologies for contract-related decision-making. This means that some roles traditionally held by humans in managing and controlling contracts will shift to algorithm- and data-driven digital

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systems. Therefore, acceptance of innovation and trust in automated systems are essential for iContract to work effectively. Without strong trust and collaboration between stakeholders, it will be difficult to implement the technology successfully.

In the environmental factors, external challenges must also be considered. These include the construction industry's readiness for digitalization, legal certainty regarding the validity of digital contracts, and the availability of necessary technological infrastructure, such as data networks, sensors, and digital storage systems. If infrastructure is lacking or legal frameworks are not in place, iContract adoption will not be widespread or sustainable. Thus, collaboration between industry players, government, and technology providers is crucial to building an ecosystem that supports full implementation of iContract.

Quality Improvement

Blockchain and smart contract technologies can be applied to improve the quality inspection process directly at construction sites. This research is motivated by the fact that quality inspections in the field have traditionally relied heavily on manual methods and individual integrity, which often lead to issues such as recording errors, data manipulation, and low accountability. In cases of disputes or audits, the available data is not always reliable, as it may be poorly documented or easily altered.

To address this, a blockchain-based system was developed using the Hyperledger Fabric platform [10]. The system is designed to permanently record quality-related data in a tamper-proof manner. With the support of smart contracts, the quality evaluation can be conducted automatically based on pre-agreed technical standards. Furthermore, the system is integrated with IoT devices to collect data directly from the construction site. Through this system, all field data can be validated and stored on the blockchain automatically, thereby reducing the potential for errors and enhancing trust among project stakeholders.

As an example, the authors deployed a blockchain platform built on Hyperledger Fabric to manage and verify on-site inspection data related to structural concrete works. Field engineers and inspectors used mobile applications to submit real-time test data, such as concrete slump, temperature, and curing conditions, which were then automatically evaluated by smart contracts based on predefined technical standards. If the data met the required criteria, the smart contract validated and permanently recorded the result on the blockchain. If the criteria were not met, the system triggered automated alerts for further action. This process eliminated the potential for manual manipulation of quality data and ensured traceable, tamper-proof inspection records across the construction supply chain. The study showed that such a system can significantly reduce administrative workloads, improve data transparency, and enhance accountability among project participants. By including technical standards directly in the smart contract, the system was able to automatically check and approve quality results in a reliable way, without needing supervision from a central authority.

Dispute Resolution

Claims and disputes are unavoidable aspects of construction project execution. A claim arises when one party believes it is entitled to compensation or a change in work conditions, while a dispute occurs when the claim is rejected or not agreed upon by the other party [11]. Unresolved disputes can significantly disrupt project progress, leading to delays, increased costs, and deteriorating relationships among stakeholders. The root causes of these issues tend to be consistent—contract ambiguities, unmanaged design changes, administrative errors, and poor communication between parties. Moreover, human factors, both technical and organizational, play a major role in the emergence and escalation of disputes.

A key contribution of this study lies in highlighting the potential of emerging technologies such as Building Information Modelling (BIM), blockchain, and smart contracts in improving claim management and dispute resolution. BIM can identify potential conflicts during the planning stage, while blockchain and smart contracts enable permanent transaction records and automatic enforcement of contract provisions. These technologies enhance transparency, accountability, and efficiency, which are the areas that are traditionally sources of conflict in construction projects.

One commonly used dispute resolution mechanism is the Dispute Adjudication Board (DAB), particularly under FIDIC contracts. However, a significant limitation of DABs is the weak enforcement of decisions that are binding but not final, often resulting in delays in implementation, increased administrative burden, and higher costs [12]. In this context, blockchain technology can be employed to permanently and transparently record all transactions, project progress, and DAB decisions in an immutable ledger. Additionally, smart contracts can be programmed to automatically execute adjudicated decisions, including the release of funds through an escrow system if one party prevails in the dispute. This approach not only accelerates and streamlines dispute resolution but also promotes

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fairness by minimizing opportunities for interference and manipulation.

Blockchain-based dispute resolution platforms such as DCENTR and Kleros adopt a crowdsourced adjudication model, in which disputes are resolved through voting by a randomly selected panel of independent jurors. These mechanisms are fully automated via smart contracts and offer low-cost, rapid, and transparent solutions suitable for small to medium-sized projects. Furthermore, such systems enable the full automation of DAB structures, including the selection of board members and execution of rulings. A notable innovation in this area is the implementation of on-chain DABs, where all operational steps are conducted digitally and without intermediaries, while still adhering to the principles of international construction law.

The implementation of this system allows smart contracts to automatically enforce decisions made by the DABs, such as identifying which party is responsible for a project delay. For example, in a simulated case involving a dispute over late milestone completion, the smart contract automatically released withheld funds to the entitled party immediately after the DAB issued its decision. All actions and records were securely stored on the blockchain, ensuring transparency, immutability, and traceability. This approach reduced the time and effort required to enforce decisions and promoted fairness by preventing data manipulation or delays. Although the system remains at the prototype stage, it demonstrates how blockchain and smart contracts can improve dispute resolution in construction projects by making the process faster, more transparent, and more reliable.

Others

Smart contracts offer significant advantages in automating critical contractual functions in construction projects, especially those related to performance monitoring and financial adjustments [13].

Automated Responsibility Attribution.

By integrating real-time data from project schedules and execution logs, which are often gathered from digital project management tools or IoT sensors, smart contracts can algorithmically determine which party is responsible for a project delay. For example, if a subcontractor fails to complete a task within the agreed time frame and the system detects this through digital logs, the contract code will flag this delay and assign responsibility without the need for manual arbitration.

Automatic Calculation of Compensation and Penalties.

Once a delay is verified, the smart contract can compute the penalty or compensation owed based on predefined parameters in the agreement, such as daily penalty rates or grace periods. This removes ambiguity in interpreting the contract terms and ensures consistent enforcement, thereby minimizing potential disputes.

Real-Time Price Adjustment via Oracles.

The system is also capable of adjusting prices dynamically based on current market data. For instance, it uses digital oracles—trusted external data feeds—to retrieve up-to-date material and labor cost indices from government databases. This allows the smart contract to apply these figures to real-time price adjustments for construction items, especially in cases where a contract includes escalation clauses to accommodate price volatility.

The smart contract system was implemented using the Ergo programming language, known for its formal verification capabilities and strong support for blockchain applications, along with the Concerto data model, which allows for modular and flexible contract logic design. It was tested in a real-world context on a large-scale infrastructure project using Hyperledger Fabric, a permissioned blockchain platform suitable for enterprise applications due to its privacy and scalability features. In practical terms, this means that if a delay occurs or material costs rise significantly, the system will:

1) Identify the event,
2) Determine if it meets the contractual criteria for financial action (such as delay penalties or price adjustments),
3) Calculate the required amounts, and
4) Automatically initiate the transfer of funds or issuance of new payment obligations.

All these actions are executed autonomously by the smart contract without manual intervention, reducing administrative burden, minimizing human error, and increasing fairness and trust in project execution.

Challenges

Although smart contracts have strong potential to support digital transformation in the construction industry, their use in real projects still faces several serious challenges. One of the biggest problems is unclear regulations. Many countries do not yet have clear legal rules about whether smart contracts are valid or enforceable. This makes companies unsure and hesitant to use them widely [9].

Another challenge is dispute resolution. Smart contracts are made to automatically carry out contract terms, but they are not flexible enough to handle

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complex disputes, which often happen in construction projects. This shows that traditional legal methods are still needed to help solve such problems.

From a technical and management point of view, using smart contracts requires new skills, especially in IT and programming. It also needs good integration with other systems like Building Information Modelling (BIM). Project managers must also change some of their current processes to work with smart contract systems. A further issue is the lack of standardization. Right now, there are no clear guidelines for how to use smart contracts in construction. This makes it hard to apply the same system to different projects. Data privacy and security is another concern. Even though blockchain keeps data safe from tampering, it does not fully protect private or sensitive data, especially data used in systems like BIM. This needs to be addressed for the technology to gain trust and be used more widely.

4. CONCLUSION

The application of blockchain and smart contract technology in the construction industry has shown great potential in addressing long-standing challenges such as delayed payments, lack of transparency, and high levels of disputes among stakeholders. Due to their transparent, automated, and tamper-proof nature, these technologies offer significant improvements in contract management, quality inspection, and progress-based payment processes.

Various studies reviewed in this paper indicate that systems such as SMTSEC, BBSC, and iContract can enhance project administration efficiency, strengthen accountability, and accelerate dispute resolution. Furthermore, integration with other technologies such as BIM, IoT, and AI broadens the potential benefits these systems can deliver.

However, this study also highlights several research gaps that need to be addressed in future research and practical implementation. One major gap is the absence of standardized frameworks to ensure interoperability of smart contracts across different projects and construction technologies. Without clear standards, widespread and consistent adoption of these technologies will be difficult to achieve.

From a technical standpoint, there are still limitations in integrating smart contracts with other digital systems used in construction projects, such as BIM. Empirical evidence of successful integration in real-world settings remains limited. Moreover, most existing studies are still at the simulation or laboratory stage, indicating a need for more case studies that test the effectiveness of these technologies in actual project environments.

Therefore, while the potential of blockchain and smart contracts in the construction sector is considerable, their full-scale utilization requires clear regulatory support, integrated technical standards, sufficient infrastructure readiness, and mature organizational adaptation. Further research in these areas is essential to bridge existing knowledge gaps and ensure effective and widespread implementation in the future.

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