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Evaluation of the Application of Smart Contracts in Construction Industry Management: A Systematic Review of Previous Research

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Abstract

The timely preparation and delivery of contractual documents are essential to the timely and successful delivery of construction projects. However, the construction industry remains dependent on complex and time-consuming conventional contracting processes, which negatively affect the final delivery and operation of construction projects. Smart contracts have recently emerged as an innovative technology and an effective alternative to conventional contracts, which are often lengthy, complex, and, in some cases, difficult to interpret. Although smart contracts have attracted increasing attention from researchers and organizations, their application remains at an early stage. While the construction industry has lagged behind other industries to some extent in rapidly adopting recent technological advances, national and international research has created numerous opportunities for technological advancement in this industry and for integrating conventional contracts with smart contracts. Construction contracts are recognized as one of the most effective instruments for allocating risks among project parties. Consequently, numerous risks challenge stakeholder organizations and institutions in adopting and implementing smart contracts in construction projects. Smart contracts provide the infrastructure required for the independent execution of predefined and mutually agreed legal terms and conditions through network-based coding. Keeping pace with technological growth and advancement is a fundamental requirement for various industries. Further efforts are therefore needed to convince stakeholder institutions and organizations that advances in blockchain technology and smart contracts can provide valuable benefits and mechanisms for construction contract management and facilitate alignment with technological development. This study aimed to examine the conditions required for integrating conventional contracts with smart contracts in the construction industry, evaluate the concepts and benefits of smart contracts in this industry, investigate the drivers and strategies that can promote and expand their implementation, review previous research on smart contracts in the construction industry, and examine the evolution of research in this field. It also investigates the characteristics, risks, challenges, advantages, and disadvantages of smart contracts. Through a detailed review of 10 domestic and 40 international articles, the study examined the various dimensions of smart contracts from different perspectives. Given the increasing competition in the digitalization of conventional contracts, the study sought to establish an appropriate perspective for implementing smart contracts in the construction industry and to develop strategies for overcoming the identified barriers.

Keywords: *contract, smart contracts, construction industry, blockchain, conventional contracts*

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1. Introduction

The construction industry plays a central role in economic development, infrastructure provision, employment generation, and the formation of the built environment. Nevertheless, construction projects continue to experience persistent managerial and contractual problems, including cost overruns, schedule delays, fragmented decision-making, inefficient information exchange, payment disputes, claims, adversarial relationships, and inadequate coordination among project participants. These problems are partly attributable to the project-based and highly fragmented structure of the industry, in which owners, consultants, contractors, subcontractors, suppliers, regulators, and financial institutions must coordinate their activities through complex contractual arrangements. Although contracts are intended to establish the rights, obligations, risks, and responsibilities of the parties, conventional construction contracts are often lengthy, difficult to interpret, and dependent on manual administrative procedures. Early investigations into stakeholders' perceptions of smart contracts showed that the construction industry's contractual environment could benefit from digital mechanisms that strengthen the reliability and efficiency of contract administration [1]. Subsequent research similarly identified blockchain as a potentially transformative infrastructure for information management, transaction recording, and contractual coordination in construction [2-4].

Traditional construction contract management generally requires numerous documents, repeated verification, centralized recordkeeping, and intervention by trusted intermediaries. Certificates, invoices, progress reports, variation orders, inspection records, and payment requests must commonly pass through several organizational levels before a contractual action can be approved. This administrative structure can produce delays, duplication, information inconsistency, and opportunities for errors or opportunistic behavior. Digital transformation has therefore become an increasingly important strategy for improving productivity and governance in the architecture, engineering, construction, and operations sectors. Within this transformation, smart contracts have attracted attention because they may convert certain contractual provisions into executable computer code. A smart contract can be understood as a digitally encoded arrangement that automatically performs specified actions when predefined conditions have been satisfied. Its effectiveness depends on accurate contractual logic, appropriate programming paradigms, secure execution environments, reliable data inputs, and compatibility with the technical and organizational systems used by project participants [5]. However, the extent to which such arrangements are genuinely "smart" remains debatable because construction contracts frequently contain subjective terms, exceptions, discretionary decisions, and circumstances requiring professional judgment [6, 7].

Blockchain technology provides an important technical foundation for smart contracts by creating a distributed and tamper-resistant record of transactions. Once contractual data are validated and entered into a blockchain ledger, authorized participants can access a shared and traceable version of the information. This characteristic may reduce disagreements regarding whether an instruction was issued, an obligation was fulfilled, or a payment became due. Smart contracts can further automate contractual actions by linking verified events to coded consequences. For example, confirmation that a construction activity has been completed and approved may automatically trigger a payment or release of retention. Therefore, blockchain-based smart contracts have been proposed as mechanisms for increasing transparency, traceability, security, and accountability while reducing dependence on intermediaries [8, 9]. Nevertheless, the potential value of these technologies should not be equated with immediate applicability because successful implementation requires alignment among legal rules, contractual language, digital infrastructure, organizational procedures, and stakeholder capabilities.

Payment management represents one of the most frequently investigated applications of smart contracts in construction. Delayed payments and insecure cash flows can negatively affect contractors, subcontractors, and suppliers, resulting in disrupted work, financial pressure, reduced productivity, and disputes across the construction supply chain. A smart-contract system designed to secure construction payments can connect the verification of completed work with the automatic execution of payment obligations, thereby reducing administrative delay and uncertainty [10]. Blockchain-based payment frameworks have similarly been proposed to automate construction payments and create transparent transaction records [11]. Research on construction supply chains suggests that smart contracts may address payment problems by establishing shared records, increasing visibility, and automatically enforcing agreed payment conditions [12]. When combined with digital project information, these mechanisms may strengthen both payment administration and overall contract management [13, 14]. Such improvements may contribute to timely project delivery by reducing processing time and ensuring that contractual actions occur when the relevant conditions are verified [15].

Building information modeling (BIM) is particularly important for the practical implementation of smart contracts because it can provide structured information regarding design elements, quantities, schedules, progress, and asset characteristics. The integration of BIM with blockchain-based smart contracts can connect physical project progress with digital contractual processes. A BIM element or activity may, for example, be associated with contractual requirements, inspection criteria, approval procedures, and payment conditions. Frameworks combining BIM and blockchain have consequently been developed to support smart construction contracts and automate specific project-management processes [16]. Research has also explored the conversion of graphical process representations into smart contract language, reducing the gap between construction workflows and executable code [17]. More recent workflow engines have extended this approach by supporting smart contract generation and visualization for construction business-process collaboration and automation [18]. The integration of managerial information with data concerning materials and project operations may therefore allow smart contracts to function as a bridge between construction management and physical production processes [19]. The growing relationship among smart contracts, BIM, and digital twins further illustrates the movement toward interconnected and data-driven construction management systems [20].

The expected benefits of smart contracts extend beyond payment automation. Their potential advantages include reduced administrative workload, faster transaction processing, improved record accuracy, enhanced transparency, lower transaction costs, more effective monitoring, stronger supply-chain coordination, and reduced dependence on intermediaries. Smart contract management may also improve productivity by limiting repetitive manual procedures and enabling project personnel to access reliable contractual information in real time [21]. Furthermore, smart construction contracts may support the economic, social, and environmental dimensions of sustainable development by improving resource allocation, accountability, and process efficiency [22]. In infrastructure public–private partnership projects, potential applications include payment management, performance monitoring, risk allocation, compliance verification, and coordination among public and private stakeholders [23]. Reviews of smart contracts in civil-engineering and construction projects have generally confirmed their potential to improve several dimensions of project performance, while emphasizing that these benefits remain dependent on implementation conditions [24, 25]. Systematic evidence similarly identifies substantial potential alongside technical, legal, organizational, and operational challenges [26].

Risk allocation and dispute management are additional areas in which smart contracts may contribute to construction management. Conventional construction contracts distribute risks among project participants, but unclear provisions, inconsistent records, delayed decisions, and disagreements about performance can undermine the intended allocation. A smart-contract-based conceptual model may improve risk distribution by translating clearly defined obligations and consequences into transparent and executable rules [27]. Smart contracts may also mitigate disputes by maintaining reliable records, automating unambiguous contractual obligations, and reducing disagreement over the timing and status of transactions [28]. Their application to decentralized construction tendering may increase transparency and reduce opportunities for unauthorized alteration or selective disclosure during bidding, although the feasibility of such systems depends on technical capacity, governance structures, and stakeholder acceptance [29]. These applications demonstrate that smart contracts are not limited to the payment stage but may support procurement, contracting, delivery, monitoring, and dispute prevention throughout the project life cycle.

Despite these potential benefits, the adoption of smart contracts is influenced by interacting technological, organizational, and environmental conditions. From a technological perspective, organizations must consider system compatibility, scalability, interoperability, data quality, cybersecurity, and the availability of appropriate blockchain infrastructure. Organizational determinants include senior management support, employee competence, financial resources, organizational readiness, and willingness to redesign established processes. Environmental factors include legal recognition, industry standards, competitive pressures, government policy, and the readiness of business partners. Research from the United Kingdom construction sector has emphasized the importance of these technological, organizational, and environmental determinants [30]. System-dynamics analysis has likewise demonstrated that blockchain adoption is shaped by feedback relationships among multiple institutional and managerial factors rather than by a single technological decision [31]. The form of the construction blockchain ecosystem—whether oriented toward open or closed innovation—also affects cooperation, data governance, and value creation [32].

A growing body of research has therefore attempted to identify the critical conditions required for adoption. Knowledge, awareness, organizational readiness, stakeholder collaboration, legal certainty, perceived usefulness, technical support, and compatibility with existing processes have repeatedly emerged as influential factors. Studies of blockchain-enabled smart contracts in construction projects have identified critical adoption factors that project organizations must address before implementation [33]. A knowledge framework has also been proposed to organize the competencies and information needed for construction stakeholders to understand, evaluate, and apply blockchain-enabled smart contracts [34]. From a decision-making perspective, the relationships among success factors are important because one factor may influence several other conditions. Analysis using the decision-making trial and evaluation laboratory–based analytic network process has helped distinguish influential success factors from those that are primarily outcomes of other factors [35]. These findings indicate that implementation should be treated as a comprehensive change-management process rather than simply as the installation of a new software system.

The barriers to adoption are equally multidimensional. Administrative risks may arise from ambiguous responsibilities, resistance to organizational change, inadequate governance, insufficient documentation standards, and uncertainty regarding how smart-contract outputs should be approved or challenged [36]. Operational barriers include difficulty in translating contractual clauses into code, the need to integrate multiple information systems, insufficiently standardized processes, and the continuing requirement for human judgment [37]. Risk factors affecting smart contract use across the architecture, engineering, and construction industry also involve legal uncertainty, technological immaturity, inadequate skills, and stakeholder distrust [38]. Studies conducted in different national settings have shown that the relative importance of these barriers may vary according to regulatory systems, market structure, technological infrastructure, and institutional readiness. Evidence from Saudi Arabia highlights both the potential of smart contracts and the contextual barriers that must be addressed to achieve successful implementation [39], while research in Malaysia similarly demonstrates the importance of preparing the industry for adoption [40].

The nature of construction contracts produces further difficulties. Many provisions depend on concepts such as reasonable time, satisfactory performance, due care, material breach, or equitable adjustment, which cannot always be reduced to deterministic logic. Variations, unforeseen site conditions, design changes, force majeure events, and disputes frequently require negotiation and professional interpretation. Accordingly, investigations into the applicability of smart contracts have suggested that not every contractual obligation is suitable for complete automation [41]. Studies of the potential use of smart contracts likewise acknowledge substantial benefits while questioning whether the technology and the industry are ready for fully autonomous execution [42]. The more realistic short-term approach may therefore involve semi-automated or hybrid contracts in which objective and verifiable obligations are executed automatically, while complex, subjective, or disputed matters remain subject to human review. This arrangement preserves managerial and legal discretion while benefiting from automation where contractual conditions can be expressed clearly.

Security constitutes another fundamental concern. Smart contracts may contain programming errors, flawed logic, vulnerabilities, or inaccurate data connections. Because blockchain records are designed to resist alteration, an error embedded in deployed code may be difficult to correct and may automatically produce unintended consequences. Smart contracts that rely on external information also require oracles to transmit data from the physical world to the blockchain. If an oracle is compromised, delayed, or inaccurate, the smart contract may execute correctly from a computational perspective while producing an incorrect contractual outcome. Reviews of smart contract security in large-scale cloud-computing construction systems emphasize the need for secure coding, verification, access control, reliable data sources, and continuous risk assessment [43]. The increased need for remote coordination and digital transactions during the COVID-19 pandemic further illustrated both the usefulness and the security implications of blockchain-based smart contracts in construction and infrastructure projects [44]. Consequently, cybersecurity, code auditing, data governance, and contingency procedures must be incorporated into implementation frameworks from the outset.

The applicability of smart contracts must also be examined within the institutional and socioeconomic conditions of developing countries. These environments may benefit considerably from improved transparency, reduced reliance on intermediaries, stronger payment security, and more traceable procurement processes. At the same time, limited digital infrastructure, inadequate regulatory frameworks, insufficient professional expertise, and fragmented construction markets may constrain implementation. Research on adapting blockchain and smart contracts to the construction industries of developing countries has emphasized the need for contextualized adoption strategies rather than the direct transfer of models developed in technologically advanced markets [45]. A case study of the Hazrat Zainab Shrine courtyard project in Karbala further demonstrated the perceived potential of smart contracts in civil-engineering projects while underscoring the importance of project-specific evaluation [46]. Similarly, research on improving standard contract terms in the Korean construction engineering industry indicates that smart contract development should be connected to the revision and standardization of existing contractual provisions [47].

The progression of the literature reveals a gradual transition from conceptual discussion to technical development and applied implementation. Early studies focused largely on stakeholder perceptions, blockchain feasibility, and the general potential of smart contracts. Later research examined automated payments, BIM integration, adoption determinants, administrative and operational risks, and systematic classifications of benefits and challenges. Systematic reviews have consolidated this expanding literature and demonstrated that construction smart contract research remains diverse in terminology, methods, technological assumptions, and application areas [48]. Recent scholarship has increasingly examined how blockchain and smart contracts can move from academic models to industry practice, highlighting the need for scalable solutions, standardization, evidence from real projects, and stronger collaboration between researchers and practitioners [49]. This development indicates that smart contracts are moving closer to practical implementation, but the gap between technical prototypes and routine industry adoption remains substantial.

Domestic studies have also contributed to understanding smart contracts in civil-engineering and construction contexts. These studies have examined conceptual models for risk allocation, project-based applications, sustainable development, payment and contract management, industrial benefits, and the general state of research. Their findings broadly correspond with international research by identifying improvements in transparency, productivity, contractual control, and project coordination, together with technical, legal, and organizational limitations. Recent reviews of domestic and international evidence have attempted to organize these findings and clarify the direction of research in civil-engineering projects [24]. Studies of smart contracts in the construction industry have also emphasized their ability to accelerate contractual performance and reduce the costs and complexities associated with conventional administration [8]. Meanwhile, research covering the architecture, engineering, construction, and operations industries has highlighted the broader implications of integrating blockchain and smart contracts throughout the asset life cycle [9].

Despite the rapid expansion of the literature, several research needs remain unresolved. First, the field lacks sufficiently standardized definitions, taxonomies, and performance indicators for comparing smart contract applications. Second, many proposed frameworks have been evaluated through conceptual demonstrations, prototypes, expert opinions, or limited case studies rather than through longitudinal implementation in active construction projects. Third, further evidence is needed regarding cost-effectiveness, scalability, legal enforceability, cybersecurity, organizational change, and the distribution of benefits and risks among project participants. Fourth, the relationship between smart contracts and related digital technologies—including BIM, digital twins, the Internet of Things, cloud computing, and artificial intelligence—requires integrated analysis. Fifth, differences among national legal systems and construction markets limit the direct generalization of findings across contexts. Reviews and meta-analytical investigations have begun to clarify common patterns, but the available evidence remains heterogeneous [25]. Accordingly, a systematic synthesis is necessary to identify the evolution of the field, distinguish established findings from emerging propositions, and develop strategies for overcoming the barriers to implementation.

Therefore, the aim of this study was to systematically review domestic and international research conducted between 2015 and 2025 to evaluate the concepts, characteristics, benefits, risks, challenges, research trends, and implementation strategies associated with integrating smart contracts with conventional contracts in construction industry management.

2. Methodology

This study is classified as documentary research. Because a descriptive method was employed and considering the nature of the data, it may also be categorized as a case-review study. To collect the required data, obtain more comprehensive explanations of the topics under investigation, and clarify the research problem, a systematic literature review was conducted. This process included library research and the examination of credible scientific sources, articles, and related studies available on online databases. The statistical population consisted of collected articles concerning smart contracts in the construction industry. Accordingly, an attempt was made to use studies published in domestic and international scientific journals between 2015 and 2025. Articles addressing smart contracts in the construction industry and published in reputable domestic and international scientific journals were examined. Following the preliminary evaluation of the articles and in accordance with the initial stages of a descriptive review, studies in which smart contracts in the construction industry constituted either the independent or mediating variable were selected. Qualitative articles that lacked quantitative indicators and articles whose indicators were insufficient for calculating effect sizes were excluded.

The search and screening process for the articles included in this study covered domestic and international studies related to smart contracts in the construction industry published between 2015 and 2025. The filtering process indicated that 2017 could be regarded as the year in which articles on smart contracts in the construction industry began to emerge, while subsequent years represented a period during which the topic gradually reached a relative level of maturity.

The Civilica and Magiran websites were selected as domestic scientific databases because of their credibility as repositories of articles and research in Iran and the access they provide to indexed publications. Springer, Google Scholar, and ScienceDirect were selected as the scientific databases for international articles. The search was conducted according to the focus, relevant field, and objectives of the study. The keywords were classified into several groups and included combinations of “smart contract,” “smart contract in the construction industry,” “smart contract in construction projects,” “project management,” and “civil engineering.” Based on these keywords, 120 results were retrieved from Civilica and 980 from Magiran for domestic articles. For international articles, 11,954 results were retrieved from Springer, 678,000 from Google Scholar, and 18,478 from ScienceDirect as of the date on which this report was prepared.

After examining the titles, articles relevant to the construction field were selected, and their abstracts were reviewed. Following keyword filtering and the screening process, 10 domestic articles were selected from Civilica and Magiran, and 40 international articles were selected from Springer, Google Scholar, and ScienceDirect. To ensure the quality of the study, the selected articles were carefully evaluated, their full texts were screened, and eligible articles were included in the review. Figure 1 illustrates the article filtering and screening process.

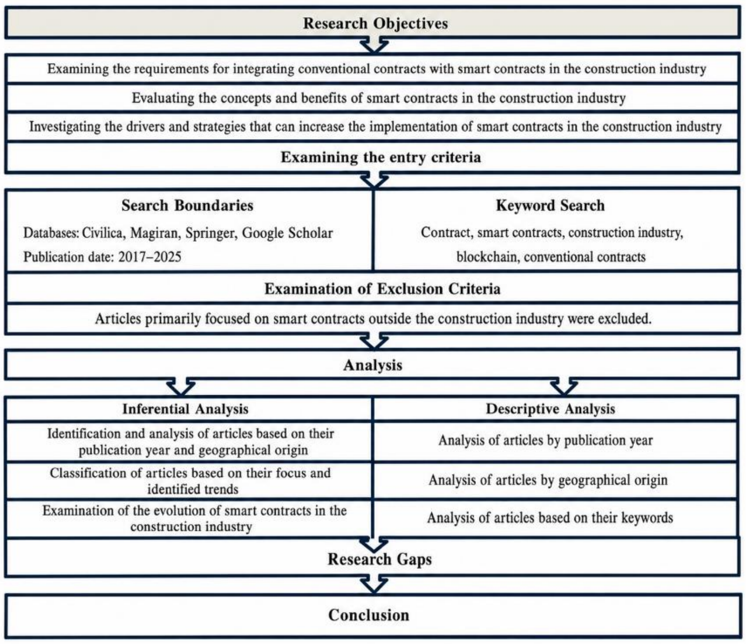


Figure 1. Article Filtering and Screening Process

In the subsequent stage, summaries of the articles—including their objectives, research methods, and conclusions—were presented as part of the literature review and subjected to descriptive analysis. The evolution of research on smart contracts in the construction industry was then examined through content analysis of the publication year, geographical origin, and keywords of the articles. This study sought to develop a better understanding of research conducted on smart contracts in the construction industry and to contribute new knowledge and explanations by identifying research patterns essential for guiding future studies. In accordance with the research objectives, attention was given to identifying the search process and relevant criteria, the data-collection method, qualitative appraisal, and descriptive and content analyses. The review identified research gaps, clarified the importance of previous studies on smart contracts and their integration with conventional contracts in the construction industry, and proposed an implementation approach based on the findings.

3. Findings and Results

In recent years, the number of studies examining the modification of conventional contracts in construction projects or their integration with appropriate alternatives, such as smart contracts capable of meeting contemporary requirements, has increased. Nevertheless, studies that have specifically sought to develop a distinct smart contract model, define detailed implementation measures, or propose other specific procedures remain very limited or inaccessible. Accordingly, the present study reviewed domestic and international research on the application of smart contracts in construction projects, including the advantages, disadvantages, and risks associated with this contractual approach.

Table 1. Summary of the Most Important Domestic Studies

No.	Article title	Authors	Year	Conclusion
1	An Investigation of the Application of Smart Contracts in Construction Projects: A Case Study of the Courtyard of Lady Zaynab in Karbala	Hassanáli Mosalman Yazdi; Mohammad Abdullah Ne'mah Al-Omar	2021	Smart contracts have considerable potential for implementation in construction projects and can improve project performance across multiple dimensions.
2	A Review of Research on the Application of Smart Contracts in Construction Projects: A Meta-Analysis	Masoud Talesh Alipour; Mostafa Ghazi Moradi; Alireza Rasekhi Sahneh	2023	The use of smart contracts in construction projects can improve overall project performance by enhancing project management and financial processes, strengthening information confidentiality, increasing competitiveness, and improving the supply chain.
3	Smart Contracts in the Construction Industry	Seyedeh Maryam Dashti; Melika Azadegan Jahromi	2023	Smart contracts can improve construction project performance by increasing transparency and the speed of obligation fulfillment, reducing costs, enabling immediate access to information and payments, and optimizing settlement and control processes.
4	An Investigation of Blockchain and Smart Contract Applications, Challenges, and Prospects in the Architecture, Engineering, Construction, and Operations Industries	Faezeh Fakharan; Hamidreza Ghasemi Rad; Elham Alikarami; Sepideh Fathi	2023	Blockchain and smart contracts can serve as transformative technologies in the architecture, engineering, construction, and operations industries by increasing transparency, trust, security, and efficiency while reducing dependence on intermediaries.
5	Effects of Smart Contract Management on Productivity in the Construction Industry	Fatemeh Sarhadi; Reza Jamal Pournajmabad	2024	The application of smart contracts in the construction industry can increase productivity and improve construction project management.

The general objectives of developing and using smart contracts are to establish a secure, efficient, and transparent system for conducting transactions and agreements; fulfill mutually agreed contractual conditions, such as payment terms; minimize waiting periods and reliance on trusted intermediaries; increase security and transparency; and reduce costs and time. In construction projects, these advantages can help alleviate problems encountered by contracting parties and make unauthorized modifications to contractual provisions impossible, thereby enhancing contractual stability and credibility.

The review of domestic and international research indicates that smart contracts are continually developing, their rules and regulations are becoming increasingly coherent, and their application is expanding. The findings demonstrated that smart contracts have considerable potential across economic, operational, legal, managerial, and technical dimensions. Significant relationships and correlations exist among these components, which may increase the potential for implementing smart contracts in construction projects. A summary of the literature and the conclusions of selected international articles is presented in the following table.

Table 2. Summary of the Most Important International Studies

No.	Article title	Authors	Year	Conclusion
1	Smart Contracts and the Construction Industry	Jim Mason	2017	Fully automated smart contracts are currently impractical in the construction industry because of project complexity, the need for human judgment, confidentiality concerns, and technical limitations. Semi-automated contracts are therefore proposed as a more realistic and appropriate approach.
2	Blockchain and Smart Contracts: A Solution for Payment Issues in Construction Supply Chains	Samudaya Nanayakkara; Srinath Perera	2021	Blockchain technology and smart contracts have considerable potential to alleviate financial and payment-related problems in the construction industry.
3	Potentials of Using Smart Contracts in the Construction Industry	Abdullah Zaki; Ayman H. Nassar	2021	Smart contracts have considerable potential in the construction industry. However, civil engineers' limited awareness and several implementation challenges currently make their fully automated application impractical; consequently, a semi-automated approach is a more reasonable option.
4	Smart Contracts in the Construction Industry: A Systematic Review	Ishara Ratnayake; Gayan Wedawatta; Algan Tezel	2022	The use of smart contracts in the construction industry remains at an early stage, but these contracts have considerable potential to improve payments, cash-flow management, logistics, transparency, and trust while reducing contractual disputes.
5	Smart Contracts in Construction: A Single Source of Truth or Mere Ambiguity?	Jim Mason; Holly Scott	2022	Under current conditions, project complexity, insufficient knowledge and training, lack of trust, uncertainty, and the need for human judgment constrain the complete automation of construction contracts. Semi-automated contracts are therefore a more appropriate and practical option.
6	Using Smart Contracts in Construction to Support Timely Project Delivery	Varsha Manwat; Lufan Wang	2023	Implementing smart contracts in construction can increase financial transparency and settlement speed, reduce costs, time, and resource waste, and minimize contractual disputes.
7	Adapting Blockchain and Smart Contracts to the Construction Industry of Developing Countries	Anuradha; Krishni Kavindya Ambagala et al.	2023	Smart contracts improve construction project efficiency by reducing delays and disputes, increasing transparency and security, lowering costs, improving project management, and enabling automated payments.
8	Smart Contract Applications for Reducing Disputes in the Construction Industry	R. M. O. H. Bandara; M. D. T. E. Abeynayake et al.	2024	By enhancing transparency and automation, reducing administrative burdens, accelerating dispute resolution, and strengthening blockchain-enabled trust, smart contracts can contribute substantially to reducing construction disputes.
9	Smart Contracts for Decentralized Tendering of Construction Projects: Challenges and Feasibility	Gabriel Nani; Emmanuel Wiriyabare et al.	2024	By establishing a decentralized and transparent platform, smart contracts can improve transparency, trust, and efficiency in construction project tendering processes.
10	Advancing Blockchain and Smart Contracts from Academia to Industry: Insights from the Construction Sector	Zhuling Ye; Liu Liu; Markus König	2025	Smart contracts have considerable potential to increase efficiency and transform the construction industry by enhancing transparency, automating contracts and payments, improving supply-chain processes, and strengthening trust.

The purpose of the descriptive analysis in this section was to summarize the principal characteristics of the data in a simple and comprehensible manner. It also involved identifying patterns and trends, enhancing research transparency and reproducibility, and preparing the data for inferential analysis.

The selected articles were also objectively examined and analyzed according to their publication year, geographical origin, and keywords. The relevant data were extracted and presented as part of the content and inferential analyses.

Analysis of Articles by Publication Year

All articles selected for this study examined smart contracts in the construction industry in some manner between 2015 and 2025. Although the concept of a smart contract was introduced in 1994, articles specifically focusing on smart contracts in the construction industry did not begin to emerge until 2017. Legal barriers, the cost of installing new systems, contract managers' unfamiliarity with smart contracts, the construction industry's slow adoption of emerging technologies, and similar factors may explain this delay. Publication-year charts were prepared separately for domestic and international articles. Figures 2 and 3 present the studies according to their publication years.

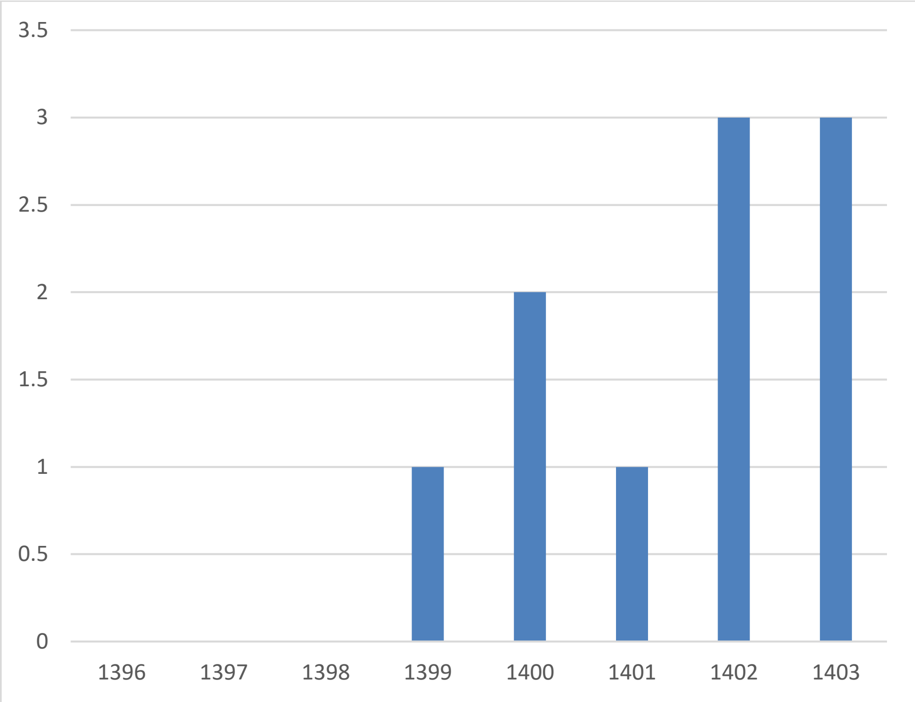


Figure 2. Selected Domestic Studies

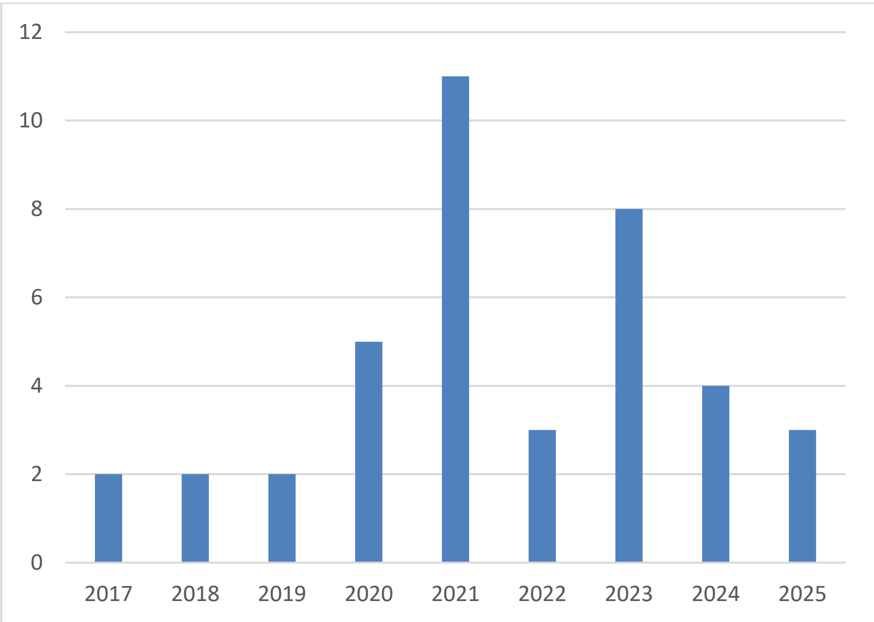


Figure 3. Selected International Studies

Analysis of Articles by Geographical Origin

To infer the geographical distribution of the articles, a literature-based examination of the countries in which the selected international studies on smart contracts in the construction industry were published was conducted according to Gregorian years. Because the geographical origin of the domestic studies was already known, domestic articles were not included in this chart. The selected international articles were chosen as a sample based on their accessibility and constituted the basis of the content analysis. Figure 4 presents the geographical origins of the selected international articles included in this study.

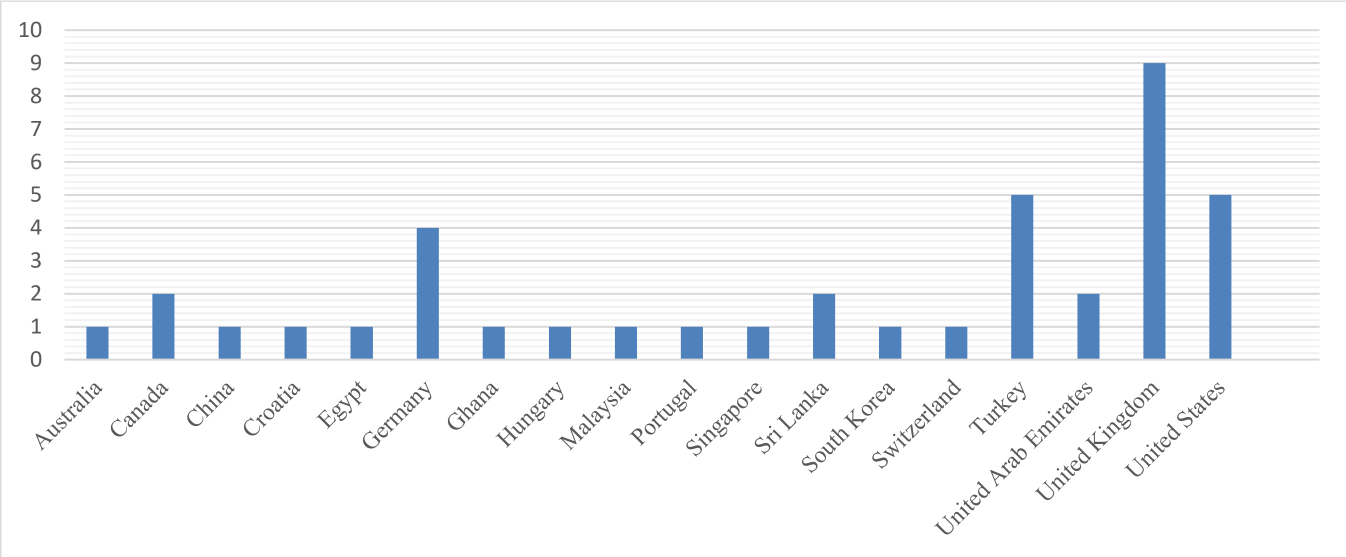


Figure 4. Geographical Origins of the Selected International Articles

Based on the number of studies conducted worldwide and the regional distribution of publications, Asia ranked first, Europe second, the Americas third, and Oceania fourth in terms of the number of articles published on smart contracts. This distribution demonstrates researchers' considerable interest in smart contracts.

Analysis of Articles by Keywords

Keywords are important research tools because they indicate the principal areas addressed by a study. Identifying frequently cited keywords in an article requires defining the research objectives and the fields under examination so that the expected objectives can be achieved. In the present study, "contract" was the most frequently occurring keyword, followed by "smart contract," "construction industry," "blockchain," and "conventional contracts," respectively.

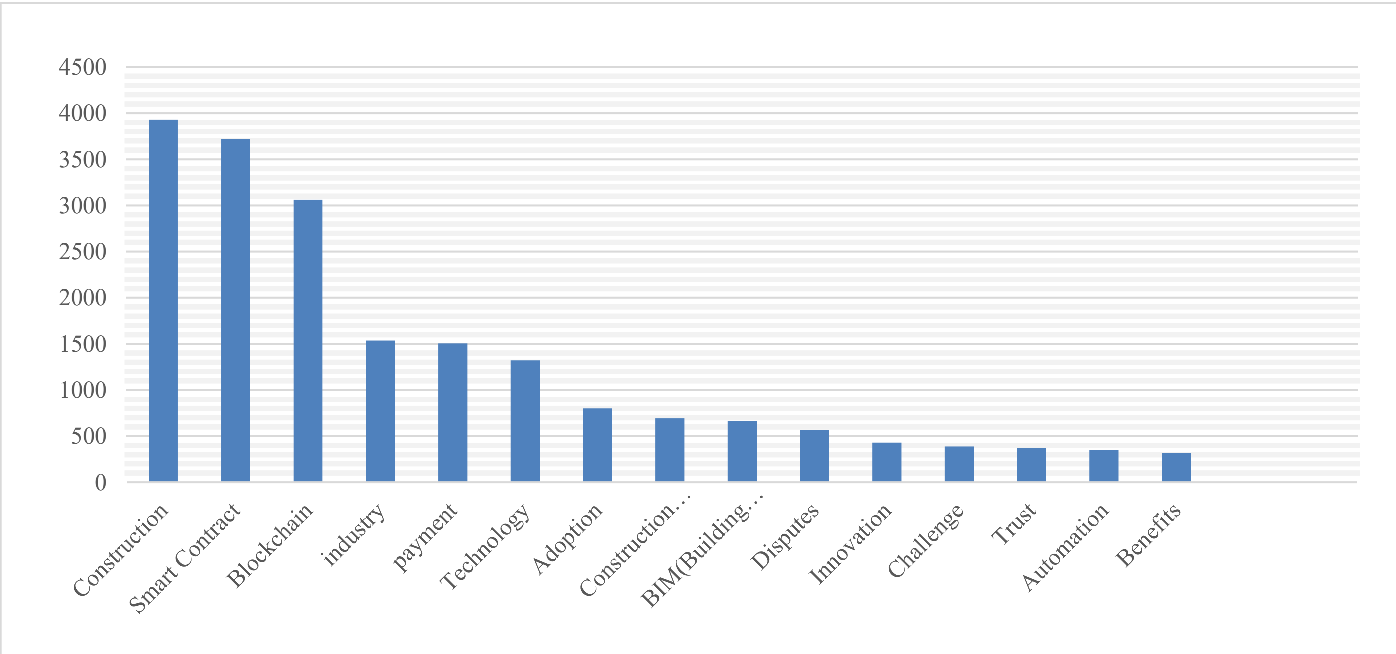
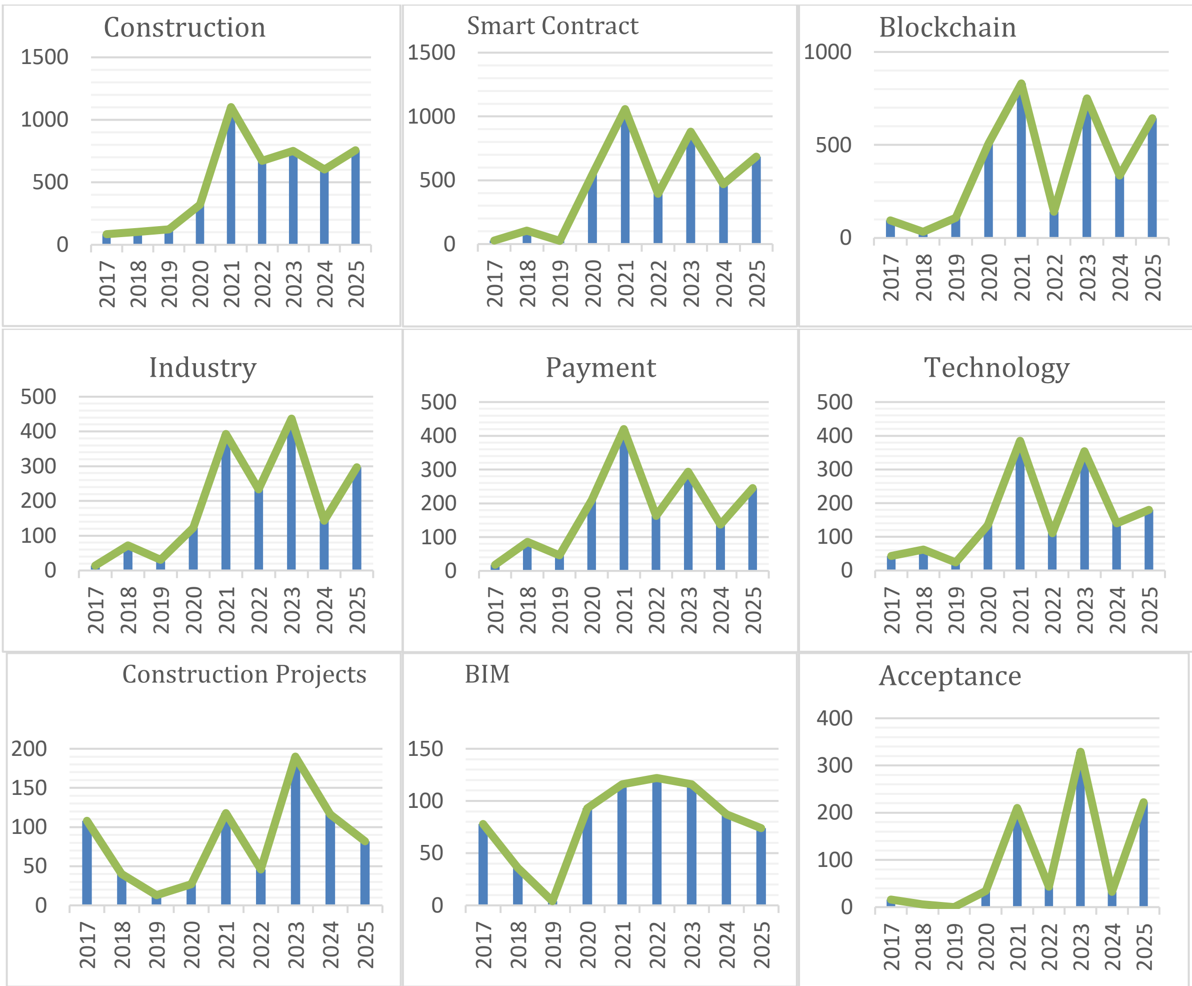


Figure 5. Analysis of Frequently Used Keywords in the Selected International Articles

In this section, inferential analysis was employed to examine more comprehensively the quality and influence of research on smart contracts in the construction industry. This analysis was intended to facilitate the generalization of sample findings, estimation of parameters, prediction of the phenomenon under investigation, decision-making, and the formulation of valid conclusions. By focusing on previous studies and their findings, extracting successful patterns, and identifying principal challenges and emerging opportunities, the analysis helps researchers recognize the strengths and weaknesses of existing approaches and develop an appropriate case model for using smart contracts in the construction industry.

Classification of Research Generations

Based on the analysis of data and previous research and the findings presented in Figure 5, the keywords employed in the relevant field were analyzed for the period from 2017 to 2025. In addition to the primary research area, these keywords included “construction industry,” “construction,” “construction contracts,” “construction projects,” “technology,” “automated construction process,” “building information modeling,” “supply-chain management,” and “construction management.” The results indicate that, with the growth of emerging technologies, the use of most of these keywords in research on smart contracts in the construction industry has followed an upward trend. This analysis, classified into three generations, provides a detailed account of the progression and research trends concerning smart contracts in the construction industry over the past decade and establishes an appropriate basis for analyzing trends and identifying future research gaps.



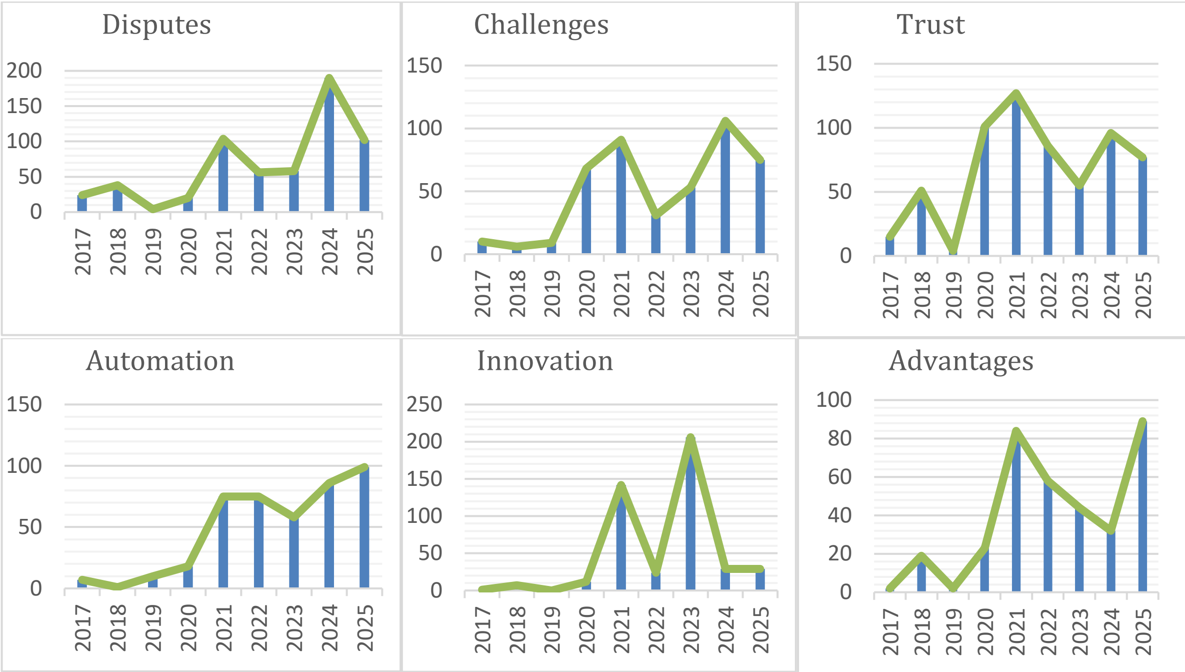


Figure 6. Frequency Distribution of Keywords Used in the Reviewed Articles by Year, 2017–2025

Based on the studies reviewed and the preceding charts, the evolutionary trend identified through the generational classification of research on smart contracts in the construction industry may be described as follows.

First generation: Conceptual emergence and the development of initial blockchain foundations (before 2017)

Before 2017, very few studies had examined the applications of smart contracts in construction. The earliest scientific articles in this area began to appear around 2017.

Second generation: Preliminary studies and growth of theoretical research (2017–2021)

Between 2017 and 2021, the number of studies concerning the use of smart contracts in construction gradually increased. The largest number of articles was published in 2021, and the upward trend continued in subsequent years.

The main opportunities and challenges reported during this period included advantages such as automation, reduced reliance on intermediaries, and improved security, as well as barriers such as organizational resistance, the absence of an appropriate legal framework, technological limitations, and inadequate compatibility with existing systems.

Third generation: Application in operational processes and technical frameworks (after 2021)

Since 2021, research has increasingly focused on technical frameworks and real-world applications. A framework has been developed for automatically generating smart contracts based on process modeling, standardization, and process visualization. This framework has also been tested in real-world contexts, such as payment processes, with favorable results. In 2023, the Dubai World Trade Centre development project used Ethereum-based smart contracts to manage payments, material procurement, and smart monitoring. The reported outcomes included a 47% reduction in payment-processing time, a 92% reduction in payment disputes, and a 28% improvement in overall supply-chain efficiency.

Table 3. Evolution of Research Generations

Generation	Period	Principal characteristics and developments
First generation	Before 2017	Emergence of the concept, initiation of preliminary theoretical research, and low adoption
Second generation	2017–2021	Growth in the publication of systematic literature reviews, concentration on key areas, and identification of barriers and benefits
Third generation	After 2021	Development of practical frameworks, integration with BIM and the Internet of Things, real-world case studies, and regional and institutional analyses

In the subsequent stage of the inferential analysis, the findings obtained from the literature review and the data extracted from the quantitative and qualitative analyses were presented to five experts in construction projects who were familiar with smart contract concepts. A brainstorming method was used to identify research gaps. In addition to familiarity with the aforementioned fields, the eligibility criteria for selecting these five experts included holding at least a master's degree and having a minimum of 10 years of professional experience. During the brainstorming session, it was stated that research on smart contracts in construction projects is increasing and expanding but has not yet reached full maturity. Significant research gaps therefore remain in this field. The principal findings are summarized below:

- **Complexity and high drafting costs:** Developing smart contracts tailored to the conditions of each project requires complex coding and the expertise of professional programmers. Although no-code platforms are available, these tools are not yet capable of designing complex contracts or gaining stakeholders' confidence. Furthermore, because contracts recorded on a blockchain are immutable, human and technical coding errors can cause substantial financial losses for stakeholders.
- **The oracle trust problem:** Contracts require real-world data, whereas blockchain systems cannot independently access information from the external world. Oracles therefore function as intermediaries. This dependence generates substantial risks, including unauthorized user access, data manipulation, and delays in data updates, raising several important questions that require further investigation.
- **Vulnerability to hacking, systemic attacks, and side-channel attacks:** Developers can improve the security and efficiency of smart contracts and reduce risks such as coding errors, overflow and underflow vulnerabilities, and inaccurate data by using reliable programming languages and algorithms, trustworthy oracles, cryptographic and mathematical-analysis methods, intermediate and preventive contracts, and third-party code audits. Examining these factors can contribute to the development of preventive solutions and improve the implementation of smart contracts in construction projects.
- **Transition from conceptual definitions to practical applications and advanced technical frameworks:** Research has gradually progressed from conceptual definitions toward real-world applications and advanced technical frameworks. However, existing legal requirements remain unclear. The absence of a distinct legal framework and incompatibility with conventional laws and regulations in certain countries create difficulties in adapting and implementing smart contracts. Further work is required to establish stronger legal and institutional mechanisms for widespread adoption, advance technical standardization, integrate smart contracts with management tools such as building information modeling (BIM), and expand real-world case studies.

4. Discussion and Conclusion

The present study systematically reviewed domestic and international research on smart contracts in construction industry management to clarify the evolution of the literature, principal application areas, potential benefits, implementation barriers, and remaining research gaps. The findings showed that although the concept of smart contracts was introduced considerably earlier, focused research on their application in construction began to emerge around 2017 and expanded more rapidly after 2021. The review of 10 domestic and 40 international studies demonstrated a progressive transition from conceptual discussions and preliminary feasibility assessments to technical frameworks, integrated digital solutions, and practical applications. The results also showed that the most prominent themes in the literature were contracts, smart contracts, the construction industry, blockchain, conventional contracts, automated payments, building information modeling (BIM), supply-chain management, and construction management. Overall, the evidence indicates that smart contracts have considerable economic, operational, legal, managerial, and technical potential, but their widespread adoption remains constrained by coding complexity, oracle-related risks, cybersecurity vulnerabilities, unclear legal frameworks, insufficient standardization, limited stakeholder knowledge, and the continuing need for human judgment.

The publication-year analysis showed that research specifically addressing smart contracts in construction was limited before 2017 but followed a generally increasing trajectory thereafter, with a noticeable concentration of studies from 2021 onward. This pattern suggests that smart contracts developed from a largely conceptual technological proposition into a distinct area of construction-management research. Early work primarily examined stakeholders' perceptions, technological feasibility, and the general relevance of blockchain to construction [1, 2]. Later studies moved toward defining practical applications, adoption determinants, payment automation, BIM integration, security, and organizational readiness [10, 13, 30]. Systematic reviews subsequently consolidated the growing body of evidence and confirmed that smart contracts had become an identifiable research stream within construction management [26, 48]. More recent research has focused on the transition from academic prototypes to industry-ready applications, demonstrating the increasing maturity of the field while acknowledging that practical implementation remains less developed than theoretical research [49].

The identified evolutionary pattern was classified into three generations. The first generation, extending to approximately 2017, was characterized by the emergence of smart contract concepts and preliminary consideration of blockchain infrastructure. During this period, construction applications remained largely theoretical because the industry lacked sufficient knowledge, technical infrastructure, contractual standards, and regulatory recognition. The second generation, covering approximately 2017–2021, involved increased theoretical research, feasibility investigations, and systematic identification of benefits and barriers. Research during this stage considered whether smart contracts were genuinely suitable for the complexity of construction transactions and whether industry stakeholders were prepared to adopt them [6, 41, 42]. The third generation, beginning after 2021, has increasingly emphasized operational frameworks, process modeling, BIM and blockchain integration, workflow visualization, and real-world implementation. This transition is consistent with studies that have converted graphical business processes into smart contract language and developed upgraded workflow engines for smart contract generation and visualization [17, 18].

The descriptive analysis further indicated that Asia produced the largest proportion of the reviewed international studies, followed by Europe, the Americas, and Oceania. This geographical distribution may reflect the combination of rapid infrastructure development, increasing investment in digital construction, and strong institutional interest in blockchain technologies in several Asian countries. Studies conducted in Malaysia, Saudi Arabia, South Korea, and developing-country contexts demonstrate that the applicability of smart contracts is receiving substantial attention across diverse construction markets [39, 40, 45, 47]. Nevertheless, the findings also indicate that implementation conditions vary substantially across jurisdictions. Differences in legal recognition, technological capacity, procurement systems, organizational culture, and professional competencies mean that a framework developed for one country cannot necessarily be transferred directly to another. The relatively smaller representation of some regions may additionally indicate geographical gaps in the evidence rather than lower potential for implementation.

Analysis of the keywords revealed that "contract" and "smart contract" were the most frequently recurring concepts, followed by "construction industry," "blockchain," and "conventional contracts." The prominence of these terms confirms that the literature remains strongly concerned with the relationship between established contractual practices and emerging blockchain-based execution mechanisms. However, the growing presence of terms such as BIM, automated construction processes, supply-chain management, digital twins, and construction management indicates an expansion from purely contractual concerns toward interconnected digital construction ecosystems. This finding corresponds with research proposing BIM–blockchain frameworks for smart construction contracts and automated contract administration [14, 16]. It also aligns with studies describing smart contracts as a bridge between construction management processes and physical materials or production activities [19]. The recent integration of smart contracts with digital twins further illustrates the emergence of data-rich and increasingly automated construction-management environments [20].

The review demonstrated that payment and financial management constitute the most mature application areas for smart contracts in construction. Conventional payment processes require the preparation, verification, approval, and transmission of numerous documents, which can delay payments and generate disputes between clients, contractors, subcontractors, and suppliers. Smart contracts can connect verified project progress with automatic payment execution, thereby reducing processing times and increasing the predictability of cash flows. This result is consistent with the smart contract payment system developed to enhance the security of construction payments [10]. It also agrees with research proposing blockchain frameworks for construction payment automation [11] and studies identifying blockchain and smart contracts as potential solutions to payment problems in construction supply chains [12]. The integration of BIM with blockchain-based smart contracts provides additional support for automated payment and contract management because BIM data can supply evidence regarding quantities, completed activities, and project progress [13]. Smart contracts may therefore contribute to timely project delivery by reducing administrative delay and accelerating the settlement of verified obligations [15].

The results also showed that smart contracts may improve transparency, traceability, trust, security, and coordination among construction stakeholders. A blockchain ledger can provide authorized participants with a shared and tamper-resistant record of contractual transactions. This shared record may reduce information asymmetry and disagreements regarding the timing, content, or validity of project decisions. The findings agree with research showing that blockchain and smart contracts may transform processes across the architecture, engineering, construction, and operations industries by reducing reliance on intermediaries and strengthening information integrity [9]. They are also consistent with evidence that smart contracts can improve project performance through faster execution of obligations, immediate access to transactional information, and more efficient control and settlement procedures [8]. At the organizational level, these improvements may translate into greater productivity by reducing repetitive administrative activities and enabling managers to concentrate on tasks that require professional expertise [21].

Another important finding concerned the potential contribution of smart contracts to risk allocation and dispute reduction. Construction disputes frequently arise from delayed payments, inconsistent documentation, ambiguous responsibilities, unauthorized changes, and disagreements concerning whether contractual conditions have been fulfilled. When obligations and their consequences can be defined objectively, smart contracts may improve risk allocation by automatically enforcing predefined rules and recording each relevant transaction. This result supports the conceptual model proposed for optimizing risk distribution in the construction industry [27]. It is also consistent with research indicating that smart contract applications may mitigate disputes by improving transparency, reducing administrative ambiguity, and providing a more reliable evidentiary record [28]. Furthermore, decentralized tendering systems may enhance transparency and confidence in procurement by recording bids and related actions on a distributed ledger, although their feasibility depends on appropriate governance and confidentiality safeguards [29]. Smart contracts may consequently operate as preventive mechanisms, but they cannot eliminate disputes arising from subjective interpretation, unforeseen events, or defective input data.

The findings revealed that the successful adoption of smart contracts is not determined solely by technical performance. Instead, implementation depends on the interaction of technological, organizational, environmental, legal, and human factors. This conclusion aligns with research in the UK construction sector demonstrating that technological readiness, organizational capacity, and environmental conditions jointly influence adoption [30]. It is also supported by a system-dynamics analysis showing that blockchain adoption develops through feedback relationships among awareness, perceived benefits, investment, regulation, and stakeholder participation [31]. Critical adoption factors include management support, technical competence, stakeholder collaboration, sufficient financial resources, system compatibility, and confidence in blockchain governance [33]. Similarly, a knowledge framework for smart contract adoption emphasized the importance of developing the knowledge and capabilities required by project participants [34]. The present findings therefore suggest that organizations should approach smart contract implementation as a socio-technical transformation involving processes, people, institutions, and technologies.

The inferential analysis identified coding complexity and high development costs as major research and implementation gaps. Construction projects differ considerably in scope, procurement method, risk profile, stakeholder structure, and contractual conditions. Consequently, designing a smart contract appropriate for a particular project may require extensive legal interpretation and specialized programming. Errors in translating contractual language into code may produce financial or operational consequences, especially when deployed code is difficult to modify. This concern is consistent with research on smart contract construction and execution, which emphasizes the importance of suitable paradigms, tools, verification procedures, and secure execution systems [5]. Although graphical modeling, reusable templates, and automated code-generation methods may reduce this complexity, such systems must still accurately represent contractual intent [17, 18]. Standard contract clauses may provide a valuable starting point, as demonstrated by efforts to develop smart contract strategies through the improvement of standard construction engineering terms [47].

Oracle reliability and cybersecurity emerged as further critical concerns. Construction smart contracts often require external data concerning physical progress, material delivery, inspections, weather conditions, or regulatory approvals. Because blockchains cannot independently verify conditions in the physical environment, they depend on oracles, sensors, BIM systems, or authorized individuals. Incorrect, manipulated, or delayed inputs can cause a contract to execute an inappropriate action even if the code itself operates as designed. The security of smart contracts is therefore inseparable from the reliability of the entire information chain. This finding agrees with research on smart contract security in large-scale cloud-computing construction systems, which stresses secure programming, authentication, access control, and vulnerability management [43]. It is also consistent with literature identifying technological risks, inaccurate data, and system vulnerabilities as barriers to construction smart contract implementation [37, 38]. Third-party code audits, multiple verified data sources, contingency clauses, and procedures for suspending erroneous execution are consequently essential.

The review also demonstrated that unclear legal status and incompatibility with conventional contractual principles continue to limit implementation. Not all construction obligations can be reduced to binary conditions. Provisions concerning reasonable performance, extensions of time, quality, negligence, variations, unforeseen conditions, and force majeure commonly require contextual evaluation. These characteristics explain why fully autonomous construction contracts may currently be impractical. Research questioning whether smart contracts provide a genuine single source of truth similarly emphasizes that code cannot remove ambiguity inherent in construction projects or eliminate the need for human judgment [7]. The findings therefore support semi-automated or hybrid arrangements in which clearly measurable obligations are automated, while complex matters remain subject to managerial, technical, or legal review. Such an approach can preserve flexibility without abandoning the benefits of transparent records and automatic execution.

Overall, the findings demonstrate that smart contracts possess substantial potential to improve construction contract management, productivity, payment security, supply-chain coordination, transparency, sustainability, and dispute prevention. These conclusions align with domestic and international reviews reporting positive relationships among the economic, operational, legal, managerial, and technical dimensions of smart contract implementation [24, 25, 46]. They also correspond with research identifying applications in infrastructure public–private partnerships and other complex project environments [23]. Nevertheless, the benefits are conditional rather than automatic. Effective implementation requires technically secure systems, legally recognized arrangements, standardized processes, reliable data, organizational readiness, and sufficiently trained stakeholders. The most defensible pathway is therefore gradual implementation through controlled pilot projects, semi-automated contractual processes, and continuous evaluation before industry-wide adoption.

This study was subject to several limitations. The review was restricted to articles accessible through the selected domestic and international databases and may therefore have excluded relevant publications indexed elsewhere, unpublished reports, dissertations, industry documents, and studies published in languages other than Persian and English. Differences in terminology may also have affected retrieval because some studies discussed blockchain-based contract automation without explicitly using the term "smart contract." In addition, the reviewed studies were heterogeneous in their objectives, methods, technological assumptions, national settings, and application areas, which limited direct comparison and prevented a uniform quantitative synthesis of all findings. The inclusion of only 10 domestic and 40 international articles may not fully represent the rapidly evolving body of literature. Finally, many reviewed studies relied on conceptual models, expert perceptions, prototypes, or limited case studies rather than completed real-world projects, so the reported benefits may exceed those achievable under routine industry conditions.

Future studies should conduct longitudinal and comparative investigations of smart contract implementation in active construction projects and evaluate measurable outcomes such as payment-processing time, administrative cost, dispute frequency, schedule performance, productivity, user acceptance, and return on investment. Researchers should develop and validate standardized assessment instruments for technological readiness, legal compatibility, organizational capacity, cybersecurity, and stakeholder trust. Greater attention should also be given to oracle reliability, code-verification methods, amendment mechanisms, error recovery, data privacy, interoperability, and the allocation of liability when automated execution produces an incorrect outcome. Comparative research across countries, procurement systems, project types, and organizational sizes would clarify how contextual conditions influence adoption. Future studies should also examine the integration of smart contracts with BIM, digital twins, the Internet of Things, artificial intelligence, and real-time project-monitoring systems. Participatory research involving legal experts, engineers, contractors, clients, software developers, insurers, and regulators could help create practical and legally enforceable hybrid contract frameworks.

Construction organizations should adopt smart contracts gradually by beginning with limited, measurable, and low-risk processes such as milestone verification, payment certification, document registration, material tracking, and selected procurement activities. Before implementation, organizations should map existing contractual workflows, identify provisions suitable for automation, assess digital readiness, and establish clear responsibility for data validation, coding, approval, and dispute resolution. Pilot smart contracts should undergo legal review, technical testing, independent security auditing, and simulation before deployment. Organizations should maintain human oversight for subjective clauses, variations, unforeseen events, and contested decisions, while incorporating emergency suspension and correction mechanisms. Training programs should be provided for managers, engineers, legal professionals, and supply-chain partners, and common data standards should be established to facilitate integration with BIM and other project-management systems. Industry bodies and public authorities should also collaborate to develop standard clauses, technical protocols, governance requirements, and regulatory guidance that support secure and responsible implementation.

Authors’ Contributions

Authors equally contributed to this article.

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Declaration of Interest

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All procedures performed in this study were under the ethical standards.

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