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Article

Risk factors affecting blockchain-based smart contract use in architecture, engineering, and construction industry

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ABSTRACT

Management of traditional construction contracts that is frequently preferred in the architecture, engineering, and construction (AEC) industries are affected by many factors due to the complexity and large number of contract documents. With the introduction of Web 3.0 technology, blockchain is considered as a suitable solution for solving many problems arising from traditional contracts and can be considered as an alternative method to traditional contracts in the AEC industry. Using cryptocurrencies, switching to blockchain-based contracts, and using smart contracts will be advantageous for AEC industry in many ways. However, in addition to these advantages, the existence of risk factors cannot be denied. With this background, this study aims to identify risk factors affecting blockchain-based smart contract use in AEC industry through a comprehensive literature review and to prioritize the identified risk factors using Analytic Hierarchy Process, respectively. The prominent risks were found to include implementation risks, followed by legal risks and contractual risks. The contributions of the study to the academic literature are the identification of the risks that may occur during the integration of blockchain-based contracts into the AEC industry and the diagnosis of any problems that may occur during the integration process. Professionals in the field of construction management can also benefit greatly from the findings of this study by analyzing those risks throughout their projects.

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INTRODUCTION

The construction industry involves very long-term work in all stages. In contract processes, the acceptance and signature processes of the parties and transferring money to the accounts take days (Di Giuda et al., 2020). Moreover, every person and institution that acts as an intermediary receives a commission and it is seen that the loss of time and money is over-much (Kim et al., 2020). The traditional contract system is affected by a lack of communication between stakeholders and defective planning and scheduling, major accidents (Chaveesuk et al., 2020). Some of the risks of the traditional contract

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system have been solved by converting this system through blockchain-based smart contracts. For this reason, smart contract applications are considered a very facilitating application for the AEC industry (Chaveesuk et al., 2020; Lamb, 2018).

A smart contract is a self-managed program used to implement automated transactions agreed by the parties (Governatori et al., 2018). It seems possible to replace this whole system with a block network by eliminating the agreements and uncertainties made with each of the stakeholders of the construction projects separately. However, new risk factors have emerged through the integration of blockchain technology in AEC industry. Considered that a construction contract management that can solve the challenges inherent in the construction industry is required (Luo et al., 2019), it is crucial to identify risk factors affecting blockchain-based smart contract use in AEC industry. Thus, the use of blockchain-based smart contracts can be learned, widespread, and used effectively in the AEC industry. The identified risks are important in terms of determining the topics to be focused on in the future studies. In addition, stakeholders know the risks they may encounter in advance and make risk management accordingly. Determining these risks will contribute to the determination of the strategy that will minimize the problems that may occur during the integration of blockchain technology into the AEC industry. For the smart contracts based on the blockchain to be understood by the project stakeholders, the risks they undertake must be identified and measured, the control points must be determined, and the risks must be prioritized.

It is a known fact that technological adaptation process of the AEC industry falls behind in comparison with other industries due to the reasons such as high complexity and structural fragmentation of the sector, the limited degree of repeatability of construction projects, weak collaboration, and insufficient investment in innovation (Sigalov et al., 2021). Although the necessity of the AEC industry to adapt to technological advancements is frequently emphasized in the literature, there are not many studies that explain the reasons behind this slow adaptation process in terms of smart contracts. On the other hand, the number of studies focusing on smart contracts is relatively few in numbers compared to the numbers of studies in other areas of construction management. In addition, these studies mostly focus on either explaining the benefits of adapting these applications for the industry or the usage of smart contracts in supply chain management, information management, and integrated asset delivery domains (Scott et al., 2020; Güven and Aladağ, 2022). This study provides literature-based information to aid in mitigating risks that arise from using smart contracts in the AEC industry. Thereby, it will be possible to contribute to the prevention of delays experienced by the AEC industry in the adaptation process to technological developments due to identified risk factors related to smart contract use in AEC industry. Thereby the usability, acceptance, and readiness of the AEC industry for smart contract use will arise. By identifying the risks, risk weights, and impacts associated with the use of smart contracts in the AEC industry, it also supports the necessary technological adaptation required by the AEC industry. This innovative approach serves as a guiding resource for industry stakeholders.

BLOCKCHAIN-BASED SMART CONTRACTS IN AEC INDUSTRY

The Fourth Industrial Revolution has quickly been changing the modern climate. The construction industry is also an example of different intermingling exercises that have occurred by coordinating arising innovations such as robots, building data displaying, expanded reality, augmented reality, web of things, and blockchain innovation. (Kim et al., 2020). The construction industry has adopted certain patterns regarding the production process for various internal and external impossibilities and practical reasons. In addition, when the developing and changing conditions are considered, restructuring is inevitable (Arslan, 2018).

The construction industry has been using formal contracts for many years to define and enforce the obligations and rights of the contracting parties (Cook and Hancher, 1990). Blockchain technology has great potential to manage contracts because it is strong against external attacks and its past transactions are almost impossible to change and the entire system works without the need for a central authority (Watanabe et al., 2016). The effective intermingling of blockchain innovation with the construction industry could lead to inventive changes by expanding the productivity of agreements and exchanges and making new plans of action (Kim et al., 2020).

For the project stakeholders to cope with the competitive environment in the construction industry, tenders must be completed successfully and result in certain profit margins for the parties. In this context, one of the priority issues affecting the performance of the projects is contract management (Odeh and Battaineh, 2002). Moreover, loss of time is a very big problem for the construction sector that requires high investment. For this reason, applications that benefit time management should be developed. Although several industries are now surveying and testing blockchain applications in their actions, its consideration in the construction industry is still inadequate and at a conceptual level (Mason, 2017).

The present studies related to smart contracts can be grouped under the headings of incorporating blockchain technology into smart contracts and integrating smart contracts into the AEC industry. Chatterjee et al. (2018)'s research is a quantitative analysis of smart contracts, and they discussed the topics describing the weaknesses of smart contracts. Although this article does not fully show the weaknesses in the AEC industry, it is important in terms of explaining the features that smart contracts have themselves. Dakhli et al. (2019) and Luo et al. (2019) figure out the potential of blockchain in the construction industry and they also mentioned the limitations of the implementation. Kim et al. (2020) also mentioned the implementation risks. Lauslahti et al. (2017)'s research focuses on implementational, technical, and legal risks. Watanabe et al. (2016), Magazzeni et al. (2017), Staples et al. (2017), Lamb (2018), Mohanta (2018), Wang et al. (2019), Yıldız (2019), and Gedik (2020)'s study helps to understand the legal aspects of smart. Likewise, Governatori et al. (2018) discussed the lifecycle of blockchain-based contracts and explained some of the problems that may occur in the process. Kemmoe et al. (2020)'s research is also about the smart contract but in a technical way. Zheng et al. (2017) and Di Giuda et al. (2020) handle the digital transformation of the construction industry. While describing the integration between BIM and blockchain, they made inferences about the integrations that can be made with the blockchain. Gurgun and Koc's (2020) study emphasize the risk challenges of smart contract implementation on construction projects, but this research focused on administrative risks. Wang et al. (2019)'s study has general information about blockchain technology in the AEC industry. Although Khatoon (2020) has discussed the use of blockchain-based smart contracts for the health-care sector, implications for the construction sector have been reached by considering the profits and losses of the current implementation. The examples of studies generally focus on the potentials, benefits, and gains of this integration, it is seen that the process needs literature support in terms of risk management.

RISK FACTORS ON BLOCKCHAIN-BASED SMART CONTRACT USE IN THE AEC INDUSTRY

In line with the aim of identifying risk factors affecting blockchain-based smart contract use in AEC industry, a comprehensive literature review was conducted. As a result, a total number of 30 risk factors were identified and classified under six groups. Table 1 shows the identified risk factors. Detailed information about the main and sub-risk factors is given in the next section.

Contractual Risks

Contract risks are listed as one of the three main criteria of directorial risks challenging the adoption of smart contracts in the AEC industry (Gurgun and Koç, 2021).

- Non-changeable contract clauses (Irreversibility): Due to its irreversibility, it should be added to the contract definition by considering all scenarios that may require changes in the contract in cases where the contracts do not meet the demands (Gedik, 2020). While technically some updates can be made, all history is recorded in the blockchain system (Wang et al., 2019; Chatterjee et al., 2018). If the contract is not carefully formulated, it is almost impossible to solve the problems that will arise (Yıldız, 2019).
- Language Paradigm: A smart contract program with no natural language equivalent can be generated. However, this can affect conflict resolution and contract formation due to the type of programming language, leaving the contracting parties alien to their own will (Governatori et al., 2018; Magazzeni et al., 2017). In addition, the translation of the smart contract, which is a "program code," into local languages carries a risk (Gedik, 2020).
- Archiving of the Contract: In addition, the irreversibility feature of smart contracts can also bring the risk that parties will not have the opportunity to negotiate the terms of the contract (Watanebe et al., 2015).
- Interpretation of the Contract: The "if/then logic" eliminates gray areas in contracts while reducing contractual conflicts. However, new conflicts may arise when the programmer misunderstands the customers' requests, and a brand-new markup language must be created to prevent this (Lamb, 2018; Magazzeni et al., 2017).
- Termination: Since smart contracts are not suitable for changes, parties that are not satisfied with the terms cannot withdraw from the contract and termination cannot be made (Yıldız, 2019; Governatori et al., 2018). In addition, to ensure security in the network in a detected vulnerability, the contract must self-destruct (Wang et al., 2019).
- Dispute Resolution: There are risk factors such as the lack of a resolution mechanism and the ineffectiveness of lawyers in the resolution of disputes (Gurgun and Koç, 2021). On the other hand, considering the bindingness of contracts, consent-based solutions can be tried in the blockchain (Governatori et al., 2018).

Financial Risks

Financial risks that may be encountered in the implementation of smart contracts are considered under five sub-risk factors such as initial cost, transactional costs, energy consumption, taxes, and attitudes toward payment of stakeholders.

- Initial Costs: The initial cost is an obstacle to the use of smart contracts and cannot be considered a cheap contract (Kandiye, 2020; Savelyev, 2017). In addition, translating the contract language to code is costly (Lamb, 2018).

Table 1. Risk Factors Affecting Blockchain-based Smart Contract Use in AEC Industry

Risk Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Freq.
Contractual Risks																							
CR-1																							
Non-Changeable Contrac Clauses (Irreversibility)	X	X	X			X												X			X		6
CR-2																							
Language Paradigm				X		X								X									3
CR-3																							
Archiving of the Contract						X	X											X	X			X	5
CR-4																							
Interpretation of the Contract	X													X	X						X		4
CR-5																							
Termination						X															X		2
CR-6																							
Dispute Resolution				X		X															X		3
Financial Risks																							
FR-1																							
Initial Costs				X			X				X				X			X					5
FR-2																							
Transactional Costs				X							X					X		X					4
FR-3																							
Energy Consumption							X	X								X		X		X			5
FR-4																							
Taxes			X																		X		2
FR-5																							
Attitudes Toward Payment of Stakeholders					X	X	X				X												4
Risk Factors	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**Freq.**
Implementation Risks																							
IR-1																							
Fluxional Nature of Construction	X	X			X	X	X	X	X	X		X	X	X	X	X	X		X				15
IR-2																							
Inconvenience to Complex and Huge Projects						X							X								X		3
IR-3																							
Pitfalls of Interoperability	X	X			X	X	X	X	X	X		X	X	X	X	X	X		X	X	X		17
IR-4																							
Unfamiliarity of Smart Contract Use	X	X				X	X	X	X	X	X	X	X	X	X	X	X		X		X		16
IR-5																							
Later Changes to the Project						X															X		2
IR-6																							
Audit Deficiencies				X	X	X															X		4
IR-7																							

Table 1. CONT.

Risk Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Freq.
Rigidity of the Smart Contract	X					X					X					X					X	X	6
Security Risks																							
SR-1																							
Dishonest Interactions	X				X			X									X			X	X	X	7
SR-2																							
Privacy Leakage	X		X	X			X	X	X							X		X		X		X	10
SR-3																							
Hacks and Theft of Cryptographic Keys	X		X				X	X			X							X				X	7
Risk Factors	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**Freq.**
Technical Risks																							
TR-1																							
Coding Errors	X					X	X	X			X	X		X		X	X	X			X		13
TR-2																							
Transaction Speed	X			X												X		X					5
TR-3																							
Storage		X		X			X	X								X		X					6
TR-4																							
Scalability	X	X		X		X	X											X					6
TR-5																							
Complex Structure	X	X	X	X		X	X	X				X				X		X	X	X			12
TR-6																							
Lawyer/ Programmer Requirement			X			X	X				X												4
Legal Risks																							
LR-1																							
Legal Status of Smart Contracts	X	X	X	X		X	X	X			X	X				X	X	X			X	X	14
LR-2																							
Determination of the Legal System to be Applied			X			X					X	X				X	X	X					7
LR- 3																							
Shortcomings of Current Legal Arrangements			X	X		X					X					X	X	X			X	X	9

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1. Chatterjee et al. (2018), 2. Dakhli et al. (2019), 3. Gedik (2020), 4. Governatori et al. (2018), 5. Di Giuda et al. (2020), 6. Gurgun and Koç (2021), 7. Kandiye (2020), 8. Kemmoe et al. (2020), 9. Khatoon (2020), 10. Kim et al. (2020), 11. Lamb (2018), 12. Lauslahti et al (2017), 13. Luo et al. (2019), 14. Magazzeni et al (2017), 15. Mohanta (2018), 16. Staples et al (2017), 17. O'Hara (2017), 18. Wang et al. (2019), 19. Watanebe et al (2015), 20. Watanabe et al. (2016), 21. Yıldız (2019), 22. Zheng et al. (2017).

Exist
Not Exist

- Transactional Costs: Blockchain transactions are not free because computing power consumes energy (Governatori et al., 2018). It is more costly to add records to the blockchain compared to traditional contracts (Staples et al., 2017).
- Energy Consumption: The blockchain system works based on computing power. For this reason, it is widely criticized in terms of energy expenditure (Lamb, 2018; Watanebe et al. 2016). One of the examples of blockchain applications, the Bitcoin network consumes enough

energy to power more than 1.3 million households according to Microsoft (Dakhli et al., 2019). The worldwide pool of computers performing cryptographic operations generates significant electricity usage, many of which do not directly produce a successful solution (Staples et al., 2017).

- Taxes: The development of smart contracts based on blockchain technology and its widespread use of it in the financial sector will bring along taxation problems in all legal transactions, such as the determination of the taxpayer, the type of income obtained, and the determination of the tax base (Gedik, 2020). With the standardization studies of blockchain and smart contracts, protocols should accelerate (Yıldız, 2019).
- Attitudes Toward Payment of Stakeholders: The relationship between the parties is characterized by the presence of asymmetric information, so conflicts that occur create distrust. The atmosphere of distrust also prevents the execution of the contract (Di Giuda et al. 2020). Although the payments made through contracts are advantageous for contractors and subcontractors, it may be a disadvantage in the process of completing the missing work for employers (Kandiye, 2020).

Implementation Risks

Aside from the deadlocks of blockchain-based smart contracts, there are also more sectoral risk elements to be brought by their use in the AEC industry. The complex processes of construction work create unpredictability. In this case, the execution phase of integration into the AEC industry also constitutes risk factors.

- Fluxional Nature of Construction: The impossibility of predicting certain construction process variations makes it difficult to execute smart contracts efficiently (Di Giuda et al., 2020). In addition to the opportunities they bring, smart contracts can also cause some damage with faulty applications, and DAO (decentralized autonomous organization) is one the example of this damage (Lauslahti et al., 2017).
- Inconvenience to Complex and Huge Projects: Gurgun and Koc (2021) emphasize the importance of the nature of construction projects and define them as unique and complex (Gurgun and Koc, 2021).
- Pitfalls of Interoperability: Blockchain research in the AEC industry is still inadequate and conceptual (Di Giuda et al., 2020). This integration has the potential to solve these critical problems in data security, storage, and transactions, especially blockchain technology (Khatoon, 2020).
- Unfamiliarity of Smart Contract Use: It is important to have basic policies and standards that protect stakeholders' rights and ensure legitimate transparency before full implementation (Lamb, 2018). Traditional technology may be considered a better option until the technology matures (Lam et al., 2007). Lack of awareness and understanding about blockchain hinders the spread of this technology and this technology dating back to 2008 is not mature enough yet (Dakhli et al., 2019; Staples et al., 2017).
- Later Changes to the Project: This factor involves requests for changes in the contract, scope changes, etc. It may be necessary to amend the contract clauses.
- Audit Deficiencies: Audits are important as distributed ledger systems will open new opportunities for automatic payments, which raise important legal issues (Governatori et al. 2018). Inadequacies in overseeing the fulfillment of contractual responsibilities pose a new risk. In a smart contract, it is difficult to determine in real life whether the code-providing performance is appropriate or whether the contract conditions are met.
- Rigidity of the Smart Contract: Due to the rigidity of the smart contract, there is a decrease in trust, communication, and interaction between the parties. Chatterjee et al. (2018) mentioned the sharp limits and immutability of the contract (Chatterjee et al, 2018).

Security Risks

Security risks are listed as one of vital risks challenging the adoption of smart contracts (Chatterjee et al., 2018; Wang et al., 2019).

- Dishonest Interactions: The security of smart contracts is in the hands of developers who cannot devote enough time and focus enough to provide this security (Kemmoe et al., 2020). Since the contract consists of code, anything hackers do is allowed within the contract (O'Hara, 2017). Malicious behavior is difficult to control because there is no effective regulatory mechanism (Wang et al., 2019).
- Data Privacy Breach: The transparency feature of blockchain technology is one of the reasons why it is rejected by many potential buyers. Institutions such as governments should protect access to sensitive data for various reasons. Establishing privacy on a blockchain is difficult due to its transparency feature, as any user can make a complete copy of all transaction history (Staples et al., 2017; Khatoon, 2019). Besides, not only transactions but also contract-related information is public, which leads to security vulnerability (Wang et al., 2019).
- Hacks and Theft of Cryptographic Keys: It has been stated that although users only transact with their own private key, there may be a privacy leak in the blockchain (Zheng et al. 2017). The private system keys of the network participants somehow fall into the hands

of the attackers, giving them the chance to reverse the transaction history or the luxury of access to the entire database (Dakhli et al., 2019). Wang et al. focused on the hacking problem in smart contracts (Wang et al., 2019).

Technical Risks

Blockchain-based smart contracts have some technical risks just because they are included in the blockchain system due to being very new and having unexplored areas (Wang et al., 2019).

- Coding Errors: Problems may occur due to coding errors in the smart contract, so the code that creates the smart contract must be flawless and error-free (O'Hara, 2017; Gedik, 2020; Chatterjee et al, 2018). The contract needs to be updated to tolerate the detected errors (Wang et al., 2019). If there is an error in the code, the contracting parties will not know about the error, but the execution of this error will now be intended by the smart contract owners without their prior knowledge (Magazzeni et al., 2017). One party will be compelled or misled to assume an unfair obligation (Lamb, 2018; O'Hara, 2017; Governatori et al., 2018).
- Transaction Speed: In today's technology, blockchain structures have high latency when transactions are validated and added to block logic (Gedik, 2020). Due to the limited block size, the speed of writing transactions also slows down (Dakhli et al., 2019). In addition, when an existing contract needs to be updated, the data in the previous contract is not transferred directly. This data must be re-entered manually, and it causes slowness and clumsiness (Wang et al., 2019).
- Storage: Another problem with blockchains is that they are not suitable for storing big data, that is, large volumes of data or high-speed data (Staples et al., 2017). The system needs data storage and bandwidth because the limited block size available slows down the writing of transactions (Dakhli et al., 2019). Due to the consensus mechanism, the transactions made at each node are stored and this storage causes the amount of data in the network to be too large (Kandiye, 2020).
- Scalability: Blockchain cannot be configured. In other words, it is also very difficult to correct errors or make other adjustments (Kandiye, 2020). Scalability is a big problem and uncertainty. Chains accumulate over time to create a larger block, and larger blocks mean larger storage space and slower propagation across the network. This carries the risk of gradual centralization. Bitcoin block size is limited to 1 MB and a block is mined every ten minutes, the time loss that this will bring leads to centralization in the long run (Zheng et al., 2017).
- Complex Structure: It is known that the high block creation speed compromises the security of Bitcoin (Zheng et al. 2017). The complex structure of blockchain technology is an issue that has been extensively studied in the literature.
- Lawyer/Programmer Requirement: Knowledge of blockchain technology should be available not only to the expert who wrote the contract but also to legal teams, IT, and management teams of companies (Lamb, 2018). In this case, tax experts will need to work with code experts to incorporate tax rules into blockchain applications (Gedik, 2020). The lack of experts who know blockchain technology and contract law and the need for these experts will be an obstacle for blockchain applications to become widespread in the future (Kandiye, 2020). There is a need for legal and administrative personnel in favor of coding the parameters of a contract by a programmer.

Legal Risks

While there might be strong market opportunities to embrace a new internet era, the law does not move into new ages with the same speed (Goanta, 2020). Regulatory bodies have not caught blockchain innovation yet, and this negatively affects the adoption of blockchain by businesses in industries (Kandiye, 2020).

- Legal Status of Smart Contracts: The legal status of these contracts is currently under debate (Staples et al., 2017, Lauslahti et al. 2017). It is expected that it will take decades for blockchain technology to have a legal standard and to determine the necessary policies in this regard (Dakhli et al., 2019). In addition, the lack of a regulation mechanism against bad behavior caused by legal deficiencies makes it difficult to control (Wang et al. 2019).
- Determination of the Legal System to be applied: It is still unclear how courts will respond to contract terms written in the form of a code as legal issues arise (Lauslahti et al., 2017). It is impossible to find a clear answer that applies to smart contracts in legal matters, and therefore, situations should be analyzed on a case-by-case basis (Lauslahti et al. 2017). One wonders how the world's financial system will cope with a company that is not registered in any state and has no employees (O'Hara, 2017). Yıldız (2019) mentioned the dangers of using smart contracts synonymously with contracts in the legal sense due to their nature (Yıldız, 2019).
- Shortcomings of Current Legal Arrangements: Due to the lack of an effective regulatory mechanism in smart contracts, malicious behavior is difficult to control (Wang et al., 2019). There is a need for a formal framework to control smart contract errors from a security point of view, as errors in smart contracts have direct economic consequences and there is no compensation for these errors (Chatterjee et al., 2018; Lamb, 2018). Rules and regulations cannot be enforced

at the same time as technological advances. It is expected that it will take decades for blockchain technology to have a legal standard and to determine the necessary policies in this regard (Dakhli et al., 2019). Since the law is open to violation due to the lack of existing legal regulations and allows many vital freedoms, especially civil disobedience, it is necessary to make changes in tax laws in parallel with technological developments (O'Hara, 2017; Gedik, 2020).

RESEARCH METHODOLOGY

There are several methods available for risk identification such one-to-one interviews, brainstorming, the nominal group, and Delphi techniques. (Chapman, 2001). To avoid the unclarity of given answers in face-to-face (or online) interviews (Voldnes et al., 2014), a qualitative and explorative approach (comprehensive literature review) was used in line with the purpose of determining potential risk factors since the subject discussed is new, the examples that have been applied are not widespread and it promises a popular research area. After then, with the aim of prioritization of the identified risk factors, study adopts Analytic Hierarchy Process (AHP) which is a commonly used Multi-Criteria Decision-Making (MCDM) method that aims to determine the best alternative by considering more than one criterion in the selection process. The stages of research methodology used in this study are as in Figure 1.

In the first phase of this study, a preliminary literature review was conducted to identify research problems, objectives, and research methods that would effectively address the research questions. During this stage, it was discovered that although the need for the AEC industry to adopt smart contracts is frequently emphasized in the literature, there are few studies that focus on revealing potential risk factors that may hinder smart contract

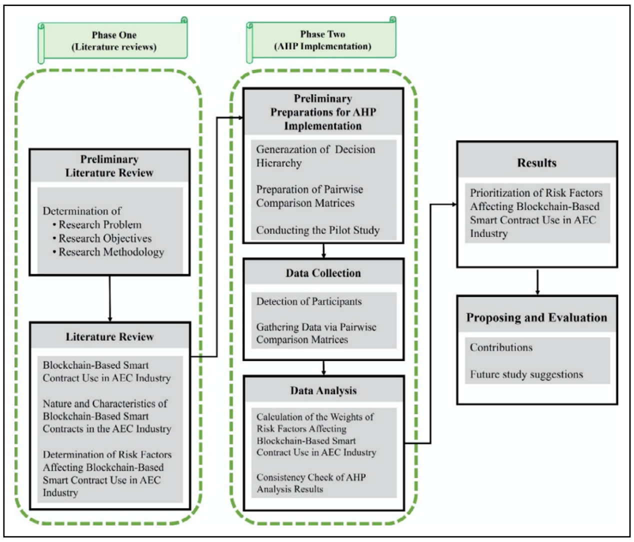

Figure 1. Research methodology stages.

adaptation in the AEC industry (Güven and Aladağ, 2022). Based on these findings, the aim of this study is to identify risk factors that impact the use of blockchain-based smart contracts in the AEC industry through a comprehensive literature review, and to prioritize these risk factors using the AHP. Afterward, a comprehensive literature review was conduction related to (1) Blockchain-based smart contract use in AEC industry, (2) nature and characteristics of blockchain-based smart contracts in the AEC industry, and (3) determination of risk factors affecting blockchain-based smart contract use in AEC industry. The previous sections present the outcomes of literature review phase. From the preliminary literature review, AHP was also determined as an adequate method in line with the aim of identifying the significance level of identified risks factors among other MCDM methods because multilateral data collection is more practical compared to other methods (Aggarwal and Singh, 2013). In addition, AHP method was selected due to (1) its ability in analyzing complex situations and making sound decisions, (2) being flexible and can be used as a stand-alone tool to resolve construction decision-making problems, (3) advantage of using a small sample size, (4) high level of consistency, and (5) simplicity (Darko et al., 2019). There are many studies using AHP method in construction management domain and one of the most common studies among these studies is related to risk management (Bigdeli et al., 2021; Kucuker and Cedano Giraldo, 2022; Cimino et al., 2023; Mandal et al., 2023).

AHP implementation starts with constructing the problem structure and pair-wise matrices of the components (Saaty, 1990). Data are relatively compared by experts in terms of certain criteria. In this way, the scale of the weights of the data is determined. AHP builds on six basic stages: (1) the composition of a decision-making problem (aim); (2) defining criteria and sub-criteria; (3) generating pairwise comparison matrices; (4) assessment of the relative value or priority of each decision criterion; (5) calculation of the weights of the criteria and priorities; and (6) analyzing the consistency (Saaty, 1990). It is possible to prioritize the available data by structuring the identified problem and thus determining priorities in line with various criteria. In this step, complex problems can be solved by comparing criteria and other possibilities and determining sub-criteria. Thus, in the second phase of the research, first, decision hierarchy (Figure 2) and pair-wise comparison matrices were generated as the Stages 1, 2, and 3 of AHP implementation.

Second, a pilot questionnaire study was carried out with the feedback of nine experts, who declared that they have advanced level knowledge of contract management and whose active years in the sector ranged from 13 to 17. The main motivations for conducting a pilot study were first to validate the determined risk factors affecting blockchain-based smart contract use in AEC industry and second to

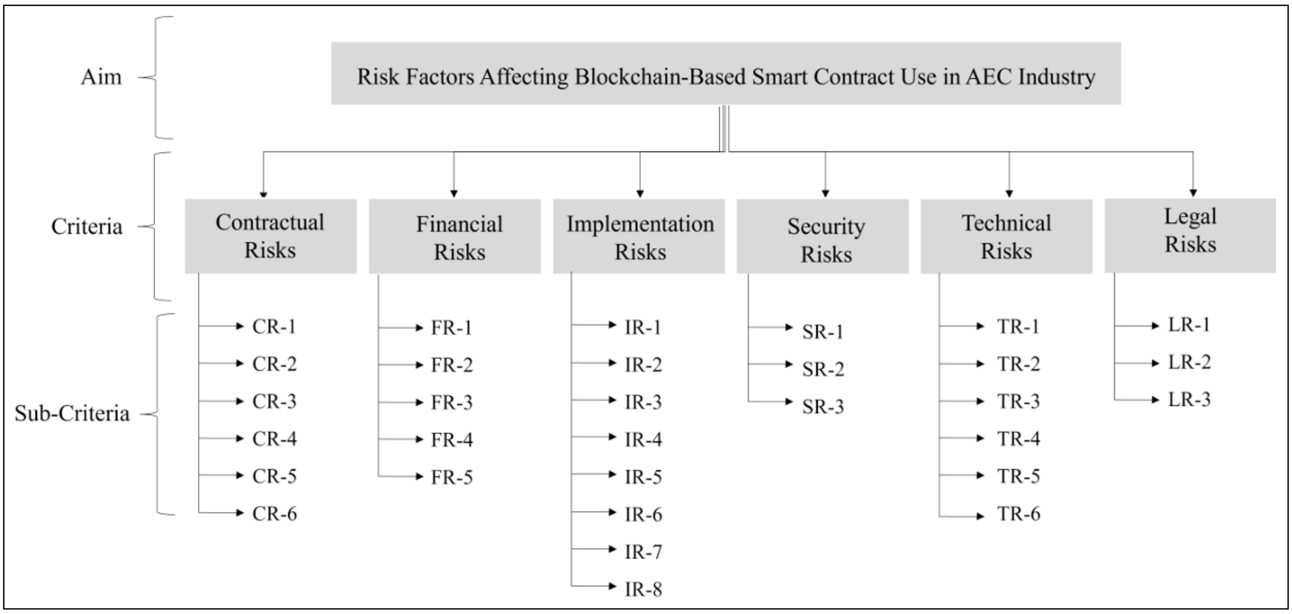

Figure 2. Decision hierarchy.

guarantee the relevance and clarity of questions related to pairwise comparison matrices. For the pilot study, first, a survey was prepared, and afterward the prepared survey file was sent to experts (pilot study participants) to request feedback within the received feedbacks. After updating the current survey based on experts' feedbacks, the pilot study was finalized (i.e.: some main titles were named with more inclusive names). The process of identifying experts was as follows: Emails were sent to the management of leading construction firms with the idea that the sought-after experts should have knowledge and expertise in contract management and technological developments. At the same time, a list of experienced experts in the construction industry was compiled through user profiles on the LinkedIn website. This list was expanded by adding experts whose names appeared in past academic studies, resulting in a contact list of more than 150 experts. As a result of the scientific research call sent to experts, some experts indicated that they could not spare the time to participate in such a study, while another group of experts refused to participate due to their lack of sufficient knowledge about smart contracts, despite their experience in the field. Some experts withdrew from the study, stating that they did not have the qualifications to provide opinions on this topic due to insufficient fieldwork on smart contracts. Hereby, the pilot study was conducted with the feedback of nine experts that voluntarily participated in the study among a compiled list of experts with a number of 150. Following the completion of the pilot study, the data collection phase was started to perform the remaining stages of AHP (stages 4, 5, and 6). The second phase of the research continues with the data collection and analysis.

DATA COLLECTION

In the data collection stage, the risk factors were compared by experts to determine the relative importance of the risks. Participants were asked to evaluate which of the two risk factors carries the greater risk for the integration of blockchain-based smart contract use in AEC Industry using Saaty's pair-wise comparison 1–9 scale (Table 2). Intermediate values of 2, 4, 6, and 8 are used in the expression of uncertainty between two options. When the decision maker is in doubt or unsure about prioritizing the data when comparing two data, she/he chooses an intermediate value. In this stage, the judgments of experts were obtained in n × n comparison matrices.

In this research, to determine the relative importance of risk factors, they were compared in pairs by both online questionnaire and questionnaires presented through face-

Table 2. Saaty's pairwise comparison scale (Saaty, 1990)

Judgments	Value
Equally important	1
Intermediate value	2
Moderately important	3
Intermediate value	4
Strongly important	5
Intermediate value	6
Very strongly important	7
Intermediate value	8
Extremely important	9

to-face interviews. Respondents were asked to prioritize the risk factors on the main criteria and sub-criteria among themselves. Within the scope of this study, data were collected through interviews that were held with five experts from the same group of pilot survey participants (The pilot survey was conducted with nine experts, while four experts could not continue with the study due to personal reasons).

AHP is based on a principle to make decisions; experience and knowledge of people are at least as valuable as the data they use (Vargas, 1990). Therefore, the small number of participants does not create an obstacle to draw meaningful conclusions from the gathered data. The small number of participants in the survey, that is, the number of samples, may negatively affect the interpretation and conclusion of the data analysis, but it is possible to obtain robust and statistically significant results since the selected samples are made up of experts using AHP (Dias and Ioannou, 1996). It should be noted that there are studies in the literature indicating that a minimum of four people is sufficient to obtain valid and reliable results in AHP analysis. In Çenet's study, a statistic related to studies including AHP in the construction management domain is available, and it is seen that generally a total number of 4–9 samples are frequently used in those studies (Çenet, 2021). The main reason for using a small number of participants in AHP is derived from the high level of experience and/or knowledge expected of the participants, which ensures valid results despite working with smaller groups in AHP method applications (Deng, 1990). Since the data in the AHP are based on expert judgments, it can be claimed that even one expert's opinion is a general representation (Golden et al. 1989). In other words, AHP is based on a principle to make decisions; experience and knowledge of people are at least as valuable as the data they use (Vargas, 1990). According to Lam and Zhao, AHP does not require the use of large samples since it is a method that focuses on a specific subject and feeds on subjective information (Lam and Zhao, 1998). The small number of participants in the survey, that is, the number of samples, may negatively affect the interpretation and conclusion of the data analysis, but it is possible to obtain robust and statistically significant results since the selected samples are made up of experts using AHP (Dias and Ioannou, 1996). However, it is still imperative for researchers to consider the AHP sample size selection with special care, as the potential impact of an optimally selected sample size on decision outcomes cannot be ignored (Darko et al., 2019). Exactly how much the identified risks will affect the AEC industry and their degree of effectiveness will be determined based on the subjective judgments of the participants, rather than a mathematical measurement. In this case, as stated in Lam and Zhao's study, since it is not easy to find and verify objective effectiveness criteria after finding them (Lam and Zhao, 2006), attention was paid to the advanced level of expertise of the selected participants. The participants' experience level in AEC industry and their knowledge level in contract management were categorized as beginner (1–5 years of experience), proficient (5–10 years of experience), and advanced (10+ years of experience), depending on their duration of experience in the sector. The competency levels of survey participants are found in Table 3.

When Table 3 is examined, the participants are eligible for ensuring the expected high experience, knowledge, and competency to make interpretations about the smart contract use in construction industry. In addition, experts in a certain region/country might have a narrower perspective on the subject due to the insufficient use and/or awareness of the smart contract concept in their respective construction industry. Therefore, in the selection of participants for AHP analysis, having experience in international projects along with experience in the construction sector and contract management was one of selection criteria. Thus, these five experts were competent to shed light on data related to the industry, as they have international project experience, not just knowledge of the use of smart contracts in a single country/region.

Table 3. Competence levels of survey participants

ID	Proficiency	Experience in AEC sector	Region	Experience in contract management
R1	Civil Engineer	Advanced level	Middle East and Asia	Advanced level
R2	Civil Engineer	Advanced level	South America, Middle East, and Asia	Advanced level
R3	Contract Manager	Advanced level	Africa, South America, Australia, Middle East, and Asia	Advanced level
R4	Construction Control Manager	Advanced level	Australia, Middle East, and Asia	Advanced level
R5	Company Owner/ Civil Engineer	Advanced level	Middle East and Asia	Advanced level

DATA ANALYSIS

After data collection, calculation of the weights of risk factors and consistency check of AHP analysis results should be performed.

The risk factors were compared among themselves to determine the relative importance of the risks obtained from the literature data. First, the identified parent risks were evaluated among themselves, and then the subcategories of these risks were evaluated among themselves. The questionnaire asked from the participants is to evaluate how important the two risk factors are over each other, through the comparison format as shown in Table 2.

With the knowledge that AHP does not require perfect consistency (Garbuzova-Schlifter and Madlener, 2016), the consistency of the obtained comparison matrices was tested. To evaluate the data of all participants together, the geometric averages of the data were taken. Conducting the contrast matrices pairwise, the consistency is found by the usage of eigenvalue, λ max, to determine the consistency index (CI). The steps required by AHP were executed with Microsoft Excel®. According to the calculations, to improve the consistency of the results containing unacceptable inconsistency, various corrections were proposed, and the survey data were updated by communicating with the survey owners. Since the subjective judgments of the decision makers are involved in the AHP method, the consistency of these judgments cannot be automatically guaranteed. For this reason, it is necessary to verify the consistency of the data (Darko et al., 2019). Consistency ratio is a checking method that should be <0.1. The CI of the participants was found as valid by taking values below 0.1. For this reason, it has been proven that the data collected is consistent. At this stage, the method of reaching the group judgment suggested by Saaty (1988) was used by including only the expert judges who were found to be consistent. Therefore, the geometric mean method was applied to obtain the consensus of the experts. Here, again, the GCR should <0.1 to prove the consideration of group judgment. Table 4 presents the importance level of main and sub-risk factors according to the AHP analysis.

According to the AHP analysis results, the most important risk factor group was found as implementation risks whereas financial risks were found as the least important risk group with an effect on blockchain-based smart contract use in AEC industry.

DISCUSSION OF FINDINGS

In this study, a total of 30 risk factors under six main risk factor groups regarding the use of smart contracts in the AEC industry were determined and AHP methodology was applied for prioritizing the identified risk factors to find their importance level in AEC industry. According to the AHP analysis results, the most important risk factor group was found as implementation risks whereas financial risks were found as the least important risk group with an effect on blockchain-based smart contract use in AEC industry.

Although information technology has advanced, various administrative risks have caused construction projects to be slow to adapt to these innovations. The application and adoption of smart contracts in AEC industry are challenging due to uncertainties, change orders, and conflicts. In the study by Gurgun and Koç, stakeholders were shown to be skeptical about the implementation of smart contracts in the AEC industry in the perspective of mentioned uncertainties and conflicts during their administration (Gurgun and Koç, 2021). Therefore, implementation risks are considered as a result that is expected to have the highest degree among prioritized risks.

Within the implementation risk factor group, "Rigidity of smart contract (IR-7)" was found as the risk factor that has the highest weight in its cluster. The rigidity of smart contracts and their refusal to accept changes or revisions are very challenging for the AEC industry, as it involves processes of constant renewal, revision, and redesign (Chatterjee et al., 2018; Kandiye, 2020; Kemmoe et al., 2020). Changes in the contractually agreed scope might require the addition or removal of certain work steps, resulting in an update of the BoQ or the billing plan (Sigalov et al., 2021). For the subsequent modification of billing arrangements, BIM and common data environment (CDE) integration is highly recommended by the authors. This integration will also provide flexibility through the versioning of the smart contract stored in a CDE and, thereby, of its internal files that are affected by the changes (Sigalov et al., 2021). On the other hand, studies suggest that changes and revision requests frequently occurring in construction projects lead to disputes between parties (Mason, 2017; Governatori et al., 2018). For this reason, it is obvious that the need for a continuous change and revision process due to the rigidity of the smart contract will create extra pressure on the parties in terms of time and cost effects. Thus, there is a need for smart contracts to show the necessary flexibility based on these revisions. However, since smart contracts do not accept a change retrospectively (irreversibility), this situation is considered as a crucial risk factor. As mitigation risk response, it is possible to carefully formulate the contract and add all possible situations that may require a change to the contract definition (Yıldız, 2019; Gedik, 2020). On the other hand, the immutable nature of smart contracts may compromise some of the rights of the contracting parties. This is because it is very difficult, sometimes even impossible, to make any changes to the smart contract that has been implemented. Although it is possible to make minor changes by adding data to the system later, this change does not mean that the relevant

Table 4. Importance level of main and sub-risk factors

Risk factors (Criteria)	Weight	Rank	Sub-Risks (Sub-criteria)	Weight	Rank	λ_{max}
Implementation risks	0.206	1	IR-7	0.211	1	0.206
			IR-6	0.158	2	
			IR-4	0.144	3	
			IR-3	0.116	4	
			IR-2	0.105	5	
			IR-5	0.103	6	
			IR-1	0.079	7	
Legal risks	0.153	2	LR-3	0.334	1	3.021
			LR-2	0.286	2	
			LR-1	0.277	3	
Contractual risks	0.144	3	CR-1	0,192	1	6.386
			CR-4	0.190	2	
			CR-5	0.171	3	
			CR-6	0.145	4	
			CR-2	0.134	5	
			CR-3	0.091	6	
Technical risks	0.112	4	TR-1	0.287	1	6.156
			TR-5	0.210	2	
			TR-6	0.145	3	
			TR-4	0.120	4	
			TR-2	0.087	5	
			TR-3	0.069	6	
Security risks	0.111	5	SR-3	0.353	1	3.011
			SR-2	0.312	2	
			SR-1	0.298	3	
Financial risks	0.080	6	FR-5	0.252	1	5.325
			FR-4	0.207	2	
			FR-3	0.232	3	
			FR-2	0.128	4	
			FR-1	0.104	5	

transactions are completely changed (Çubukçu, 2021).

According to the AHP results, "Audit Deficiencies (IR-6)" was found as the second important implementation risk that influences smart contract use in the AEC industry. Audits are important as inadequacies in overseeing the fulfillment of contractual responsibilities might pose a new risk in terms of determining whether the code-providing performance is appropriate or whether the contract conditions are met. It does not seem possible for the code that enables the execution of smart contracts to determine whether the performance is appropriate or whether the contract conditions are met. In this case, there is a need for experts called "oracle" to intervene in the smart contract process (Çubukçu, 2021). The concept of Oracle is defined as a system that determines whether the contractual obligations are duly fulfilled and meets the external needs that occur outside the blockchain. As an example, one of the application areas of blockchain-based smart contracts in the construction industry is progress payments. Automating these payment processes has been deemed meaningful by experts (Governatori et al., 2018). However, these payments should also include the verification of whether the performance subject to payment meets the required level as stipulated in the contract. As this verification presents a challenging factor in the implementation of smart contracts, the importance for its integration into the smart contract use should be attributed.

Taken into account that smart contracts are established and enabled on the internet, it is difficult to draw the legal limits of these contracts (Çubukçu, 2021). Thus, questions regarding (1) What should be considered for smart contracts to be valid contracts under the law of contracts? and (2) How legal principles can be applied to smart contracts? should be clarified. The results of the AHP analysis also reveal the importance of "Shortcomings of current legal arrangements," "Determination of the legal system to be applied," and "Legal status of smart contracts" and since these legal sub-risk factors have a high significancy level among other sub-risk factors in general. The integration of smart contracts into legally binding construction contracts presents a challenge due to the lack of legal precedents and regulations so far. Thereby, semi-automation is strongly recommended as a suitable compromise for offering a legally compliant and feasible solution for legal compliance (Sigalov et al., 2021).

Technical issues are the source of important risks that may be encountered in smart contracts. Smart contracts, which consist of a computer program, can bring some problems with them due to their technical characteristics. The AHP analysis result also highlights this issue since coding errors were determined as an important technical risk with a weight of 0.287 within its cluster. For example, it is not possible to completely prevent the possibility of typing errors in computer codes and probability of being hacked due to these code errors (Çubukçu, 2021). Thus, it may be considered that it is a more acceptable approach to compromise the immutability feature of smart contracts in certain situations to prevent events that may cause greater damage. Another risk mitigation measure can be the artificial intelligence (AI) integrations for complete human error-free smart contracts (Gupta et al., 2020).

According to the AHP analysis results, financial risks were found to as the least important risk group with a weight of 0.080. The rankings of sub-financial risks were determined as attitudes toward the payment of stakeholders, taxes, energy consumption, transactional costs, and initial costs, respectively. The use of smart contracts in the construction industry, much such as the use of BIM and laser scanning technologies requires a technological adaptation. For that kind of technological adaptation often requires high-cost items for making these systems viable (Savelyev, 2017; Lamb, 2018; Kandiye, 2020). In this context, it is an unexpected result that such high-cost items are not considered as a major obstacle by experts. The reason behind this finding might arise from the judgment of experts specific to large-scale companies. Notwithstanding for many SMEs cost issues would be among the important barriers to invest in new IT infrastructures or new software that is required for the use of smart contracts (Sigalov et al., 2021).

Stakeholder attitudes toward payment were identified as the riskiest financial factor. It is inevitable that this technology, which has not yet proven its legal status and has not been clearly accepted by the countries, carries risks in terms of taxation (Gedik, 2020). Based on the two prominent criteria, it can be stated that these results stem from the experts' handling of risk choices within the scope of the projects they are involved in. It has also been stated through the literature in the previous chapters that the implementation processes are the most challenging phase of the construction projects. In addition, it can be stated that the difficulties caused by the nature of smart contracts are considered a risky option based on the contract experiences of the experts.

According to the AHP results, it was found that "Contractual risks" have moderate importance in affecting smart contract use in AEC industry. When the sub-risk factors defined under this category are examined (non-changeable contract clauses, language paradigm of the contract, contract interpretation, termination, and dispute resolution), these risk factors can be considered as one of the most important obstacles regarding smart contract use in AEC industry (Çubukçu, 2021). For instance, Yıldız considers the misformulation of smart contracts to be a major problem, stating that solving the resulting issues is nearly impossible (Yıldız, 2019). Similarly, Governatori et al. argue that if smart contracts are unable to provide desired changes, the parties may not be able to withdraw from the contract or terminate it, which is seen as a major barrier/obstacle to the use of smart contracts (Governatori et al., 2018). Despite the findings of studies emphasizing the contractual risks as the crucial barriers/obstacles associated with smart contract adaptation, it is surprising that expert responses prioritize contractual risks at a moderate level. This may be since the focused more on problems related to the adaptation of smart contracts rather than contractual issues. However, another possible reason for why these risks were not perceived as strong threats by the interviewed experts could be the lack of adequate IT knowledge regarding the coding and technical specifications that smart contracts require.

Finally, open-ended questions asked to the experts also open new doors to examine the subject of our article. All the experts involved in our study stated that smart contracts have enormous potential as technological innovation. They stated that smart contracts and the integration of the AEC industry can be used in processes such as material procurement, material selection, supply chain, and contract management. While one expert emphasized the possibility that the use of smart contracts outside the supply chain would not be efficient enough, another expert stated that smart contract integration would only be fully efficient for information technology. It was stated that with a new system created by smart contracts, integrations such as BIM, and AI, great innovations can be brought to the construction industry. In addition, it was emphasized that the information infrastructures established in this way are a factor that protects the rights of stakeholders, facilitates the resolution of disputes, and prevents the realization of illegal practices. On the other hand, when we look at the time that experts predict for smart contracts to be integrated into the AEC industry, it is seen that experts state that this integration may take 10–20 years. The reason for this situation was expressed as the conservative structure of the AEC industry.

CONCLUSION

As digitalization becomes more widespread, the AEC industry will have to evolve with changes in contract culture. Since existing contracts do not seem suitable for digitalization, a change to be experienced in the light of technological developments is inevitable. Thus, with the developed uses of blockchain innovation, emerging smart contracts in the AEC industry have turned into a hot examination point both scholarly and practically.

With the implementation of smart contracts based on blockchain in construction projects, the dilemmas of traditional contracts can be solved, and institutions and authorized persons can be held accountable on a public basis. This technology will be active in many sectors soon and will become widespread in the construction sector as well. However, currently, the use of blockchain-based smart contract applications in the AEC industry is still in the development stage. Hence, this study is designed to identify the risk factors that affect blockchain-based smart contract use in AEC industry through a comprehensive literature review and to prioritize the identified risk factors using AHP, respectively. The five prominent risks were found as "Shortcomings of current legal arrangements," "Determination of the legal system to be applied," "Legal status of smart contracts," "Coding Errors," and "Rigidity of smart contract." It is seen that out of five, top three is related to legal issues. Moreover, the future of smart contracts is fraught with legal risks correspondingly. Semi-automation can be a suitable compromise for offering a legally compliant and feasible solution for legal compliance. In addition, concepts like.

Oracle, which is a third-party service, should be adopted for indicating whether the code-providing performance is appropriate or whether the contract conditions are met. On the other hand, smart contracts should be supported with BIM implementation to provide flexibility through the versioning of the smart contract and, thereby, of its internal files that are affected by the changes. AI integrations are highly supported to provide coding errors in terms of provide human error-free smart contracts.

Identification of these factors is crucial to get efficiency from smart contracts and to achieve an effective project management performance since project risk management has a direct effect on project management performance. These findings from this study suggest the role of smart contracts' risk factors in promoting blockchain technology adaptation decisions in the AEC industry. Besides, this study is important to recognize the adoption of smart contracts and has provided useful insight to prioritize the risk factors. The study is also at a point that makes a difference in terms of the approach to increasing industry awareness.

The future practice of the AEC industry could benefit from the findings of this study. Especially the top management of AEC firms could recognize their vital role in the implementation of smart contracts in the industry. They can enhance their competence in smart contract technology by giving a primary focus on the identified risk factors. The sectoral and academic contributions of this study can also be summarized as follows:

- As a sectoral contribution of this study, the determination of risks related to smart contract use in the AEC industry, the determination of risk weights, revealing of the risk effects are important basis for the effective risk management for industry practitioners. Additionally, the literature knowledge and expert opinions presented in this study will support sector professionals in understanding the risks related to smart contract adaptation at an early stage and help the AEC industry become more technology driven. This pioneering approach supporting the use of smart contracts in the construction industry will also be a guide for industry stakeholders.
- The academic contribution of the study on the other hand is based on its ability to address the gaps identified in the preliminary literature review. Existing studies have focused on the challenges, validity threats, and outcomes associated with the integration of smart contracts into the AEC industry (Güven and Aladağ, 2022). However, there has been no publication specifically dedicated to the risk management domain related to this integration, and no literature has prioritized these risks with a holistic approach or interpreted these risks based on expert opinions. In addition, identifying prioritized risks is crucial in terms of being of great benefit for the researchers who want to develop smart contract adaptation models for the construction industry since the integration of risk mitigation measures to eliminate prominent risk factors might be essential for this kind of Technology Adaptation Models.

The limitation of the study is that the use of smart contracts in the AEC industry is still very new, as well as the problem of access to experts in the AEC sector who have a good grasp of the subject of smart contracts. In the future studies, depending on the increase in smart contract use in the AEC industry, data can be collected from a growing number of experts, and it can be examined whether there is a differentiation in the importance level of identified risk factors. In other words, in the future studies, more general and valid results can be obtained with studies with more participation.

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