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Assessment of Barriers to the Implementation of Smart Contracts in Construction Projects—Evidence from Turkey

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Abstract: Despite their promising potential, the level of implementation of smart contracts is not at the desired level. To expedite the acceptance and deployment of smart contracts, the barriers to the implementation of smart contracts should be revealed. Past studies, however, do not provide a comprehensive theoretical basis due to several methodological drawbacks. Thus, this study aims to identify and assess the barriers to the implementation of smart contracts by considering the inherent characteristics of the construction industry. An in-depth literature review was initially conducted to extract all barriers proposed in the literature. Then, focus group discussion (FGD) sessions were conducted with the participation of the construction practitioners. In the FGD session, the results of the literature review were validated, and nine additional barriers were proposed. Finally, a total of 20 barriers under five categories was proposed for the smart contract adoption in the construction industry. Then, a questionnaire survey was conducted with the participation of 15 construction practitioners. Lastly, fuzzy VIKOR analysis was performed to assess the criticality of the implementation barriers. This study indicates that the construction companies should overcome not only technical barriers but also managerial barriers. Changes in the processes arisen due to smart contract implementation prevent the construction from implementing a smart contract, since the employees show resistance to these changes. Furthermore, the companies believe that they can lose their bargaining power with smart contracts, and they do not want to lose their power. Bottlenecks are considered the most critical barrier from a technological perspective, and companies are concerned about the problems resulting from them. Although this study provides insights into the barriers to smart contracts in the construction industry, all the respondents are from Turkey. Therefore, some of the findings of this study can be specific to the Turkish construction industry.

Keywords: civil engineering; construction management; construction projects; smart contracts; implementation barriers; contract management; fuzzy VIKOR; multi-criteria decision making (MCDM)

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1. Introduction

In all projects, a contract should be prepared beforehand to define the obligations of all contracting parties to complete the project in accordance with the expectations of stakeholders [1]. However, contract administration in construction projects is a challenging task, and most construction companies fail to manage their contracts and encounter many problems [2]. Firstly, most construction contracts have many ambiguities and inconsistencies stemming from the uncertainties of construction projects [3]. In addition, construction contracts are complicated and voluminous due to the temporary nature of construction projects, a lack of trust among contracting parties, and numerous regulations and laws [4,5]. Therefore, the parties may not understand their contractual duties appropriately. Furthermore, the relationships between stakeholders are generally opportunistic and adversarial in the construction industry [6], so establishing trust between the contracting parties is challenging in construction projects, which, in turn, can escalate claims and

disputes. Considering that the dispute resolution process usually disrupts commercial ties and/or business relationships between the parties and has serious consequences for the reputation of the parties involved [7,8], prevention and/or reduction in claims and disputes is of paramount importance for construction project success. However, although claims and disputes trigger many irreversible and detrimental problems in construction projects, traditional contract management practices fail to reduce claims and disputes [9]. The latest report presented by Arcadis [10] also revealed that construction disputes have skyrocketed recently. Furthermore, the coronavirus pandemic (COVID-19) and its control measures further fuel claims and disputes in construction projects [10,11]. Traditional contract management does not establish a productive atmosphere to prevent and resolve conflicts arising from unplanned and indefinite elements [12,13].

The main problem with contracts is vagueness; therefore, companies believe they can mitigate contract-related problems by maximizing clause clarity and using less terminology in drafting [14]. However, the human factor in contract administration can still lead to misinterpretations [14]. Automation in contract management can remedy human errors, since manual interfacing and misinterpretation of contractual clauses can be eliminated with automation [15]. Therefore, efforts are currently devoted to developing automated contract management systems. One of the latest advancements in contract management is smart contracts. Smart contracts are computer programs or transaction protocols that automate the execution, control, and documentation of events and activities in accordance with the conditions of a contract or agreement [16]. According to Savelyev [16], smart contracts should have six features: (1) solely electronic nature; (2) software implementation; (3) increased certainty; (4) conditional nature; (5) self-performance; and (6) self-sufficiency.

Smart contracts have promising benefits for construction projects since they are capable of automating the transaction protocols to achieve contractual conditions such as interim payments, liens, and confidentiality while minimizing the need for trusted intermediaries [17]. By adopting smart contracts, companies can reduce exchange and transaction costs, obtain continuous as-built cost information, achieve more clear and transparent communication, eliminate human intervention to perform fast and efficient processes, and have more secure transactions [18,19]. Despite these benefits, smart contract applications in the construction industry are not at the desired level [20,21]. The main reason could be existing barriers, which are roadblocks that companies must overcome and which negatively affect their intentions regarding smart contracts [14]. Therefore, revealing the barriers to smart contract implementation is crucial for expediting their acceptance and deployment in the construction industry. Identification and assessment of smart contract barriers can lead to more effective solutions and strategies that ease smart contract implementation in the construction industry. In other words, the probability of successful smart contract applications can be maximized. This, in turn, can increase smart contract demand in the industry. On the other hand, unsuccessful smart contract applications due to existing barriers can hinder the wider application of smart contracts in the construction industry due to the emergence of prejudice against the applicability of smart contracts.

Although researchers as well as construction practitioners have been investigating smart contracts [21], the existing studies do not present a comprehensive investigation of the barriers to smart contract adoption. The barriers were generally addressed as part of their studies, and they did not examine them deeply. Therefore, in these studies, a limited number of barriers is revealed and limited insights are provided. For instance, McNamara and Sepasgozar [14] uncovered 14 barriers. Furthermore, some studies just analyzed the literature to identify barriers. For instance, Elghaish et al. [22] identified barriers to the implementation of blockchain and smart contracts based on a literature survey. Some of the authors extracted barriers from interviews conducted with experts. For instance, Mason and Escott [23] used quotations from their interviews to reveal obstacles to smart contract adoption. Similarly, McNamara and Sepasgozar [14] prepared a list of barriers based on quotations from interviews. In other words, the authors did not utilize more advanced quantitative techniques such as FGD. FGD participants can discuss the

subject deeply, which may lead to additional insights and ideas. Therefore, FGD has the potential to increase results' reliability and comprehensiveness [24]. In addition, the existing studies neglected to consider the barriers' importance. The relative importance of barriers enables decision makers to identify significant areas of smart contract adoption that necessitate urgent resource allocation. In this way, companies can allocate their resources more effectively, which facilitates smart contract adoption. Lastly, fuzzy set theory and multi-criteria decision-making (MCDM) methods, which allow the evaluation of factors considering more than one criterion at the same time, were not adopted in the existing studies. Therefore, the reliability of the results was adversely affected due to the vagueness and uncertainty of subjective expressions given by decision makers [25,26]. Consequently, the existing literature does not investigate smart contract barriers deeply; therefore, practitioners struggle to develop a systematic approach to eliminating them and must rely on intuitive judgments when adopting smart contracts.

To address this knowledge gap, this research aims to identify the most significant barriers to smart contract adoption in the construction sector, resulting in a thorough grasp of relevant barriers and viable solutions to aid academicians and professionals in this field. Thus, professionals can develop more effective strategies by focusing on the most critical barriers instead of all barriers. Furthermore, this study provides additional barriers which are not noticed in the literature; therefore, other academicians can advance their studies by including these barriers. In addition, this study employs a robust and versatile methodology. The proposed methodology can be used for innovative technologies and/or industries by other researchers to acquire reliable findings.

2. Theoretical Background and Research Motivation

Innovation is critical to achieving higher economic growth, gaining a competitive advantage in an intensely competitive environment, and delivering higher standards of living [27]. However, innovation adoption is a challenging process, and most companies struggle to implement these innovative solutions, since, according to complexity theory, various barriers emerge as complexity rises. In other words, businesses confront different barriers while applying innovation, so they should take steps to overcome them [28], especially due to the complex and conservative nature of the construction industry, these barriers can be more challenging. Therefore, many studies have been conducted to investigate barriers to innovation in the construction industry. For instance, Rahman [29] examined barriers to implementing modern methods of construction using questionnaire responses from the U.K. and China and identified seven interrelated components. They proposed that companies could overcome these barriers by following an integrated and holistic strategy. Similarly, Nguyen [30] explored barriers to innovation for different sizes of construction organizations. This study proposed 17 barriers to innovation and categorized them into four groups: organizational, human resources, economic, and market barriers. They focused on the internal processes and assets of the companies as well as the external factors that could influence their operations. In other words, these barriers can be classified as internal or external. This perspective is also adopted in different studies about innovation [28,31]. Mojumder et al. [28] explain the classification by considering institutional theory.

The other essential issue for examining barriers to innovation is ranking barriers. For instance, Madrid-Guijarro et al. [32] ranked 15 barriers to innovation using descriptive analysis for Spanish small and medium manufacturing enterprises. Similarly, Suprun and Stewart [33] investigated the Russian construction industry to determine the most critical barriers to innovation among 16 barriers based on the Spearman rank correlation test. By using a qualitative exploratory case study, Alshwayat et al. [34] identified the top barriers to innovation in a Jordanian commercial case bank.

As an innovative solution, companies also face many barriers while implementing smart contracts. Some of the researchers focused only on external barriers and argued that the present market conditions are not appropriate for smart contract adoption. In particular, the present legislative system is regarded as a major barrier. Hsiao [35] examined smart contracts' applicability by considering existing laws. The author concluded that, due to the existing challenges in smart contract implementation, the possibility of a paradigm shift from traditional contracts to smart contracts is low. Agapiou [36] identified four legal barriers to smart contracts for construction companies. The researcher mentioned legal concerns about smart contract enforceability, data protection and privacy, intellectual property rights, and dispute resolution. The author evaluated these barriers based on the literature.

Since the smart contract is a recent technology, there are also barriers related to the technological side of the smart contract. Singh et al. [37] identified contract functionality, verification, security, and privacy as the most significant barriers based on a comprehensive literature review. Similarly, Zou et al. [38] evaluated the smart contract development stage and revealed 28 challenges that smart contract developers confronted by conducting interviews and surveys. They considered these challenges in five major categories: security, existing tools, programming languages and virtual machines, performance, and online resources.

Some studies focus on technological and managerial barriers, simultaneously. For instance, Inty and Comes [39] focused on barriers to smart contracts in the humanitarian supply chain. The authors identified barriers based on a literature review and categorized them into three contexts, namely organizational, technological, and environmental contexts. They asserted a total of ten barriers. In addition, they validated these barriers and their categories by conducting interviews with two experts from the United Nations International Children's Emergency Fund (UNICEF) and the World Food Program (WFP). Similarly, Khan et al. [40] identified five challenges of smart contract adoption in technical and usage points of view based on a literature review. According to them, the companies should overcome legal issues, reliance on off-chain resources, immutability issues, scalability issues, and consensus mechanism issues.

Although there are studies in the literature that investigate the barriers to smart contracts, the number of studies on smart contracts in the construction industry is limited [41]. However, due to its unique and dynamic nature, the applicability of studies conducted in other industries to the construction industry is questionable. Construction companies may face several barriers not considered in other industries. Additionally, the criticality of existing barriers can differ between the construction industry and others. In other words, each industry can have distinct critical barriers, so they may have different management plans to deploy smart contracts effectively. For the construction industry, McNamara and Sepasgozar [14] determined barriers to intelligent contract implementation by conducting interviews with five Australian experts from the construction industry. They determined seven factors relevant to intelligent contract implementation and barriers in the construction industry. However, intelligent contracts and smart contracts have distinct features; therefore, these terms cannot be used interchangeably [42]. Mason [18] stated the difference between an intelligent contract and a smart contract according to the automation levels of these contracts. Mason [18] defined an intelligent contract as a system that seeks to manage itself. Although McNamara and Sepasgozar [14] identified some barriers to intelligent contracts, they did not rank these barriers; therefore, they do not reveal any insights into the most critical barriers. The other study about barriers to smart contracts in construction was conducted by Lamb [43]. This study provided a general view of the potential barriers, such as over-emphasized cost reduction, high energy consumption, a lack of expertise in the market, data quality problems, and technical issues. Although this study provides a list of barriers, they ignore the criticality level of these barriers. Mason and Escott [23] conducted a study for the United Kingdom's construction industry and identified a limited number of barriers to the smart contract adoption by citing the interviewees' comments

and they concluded that expensive drafting, standardization issues, bugs, and cyber threats are the main reasons for slow implementation. Hamledari and Fischer [44] proposed that the centralized control mechanisms and lack of guaranteed execution are barriers to automation that can be performed by blockchain-enabled smart contracts. Some other studies stated additional barriers to smart contract adoption in the construction industry, such as Elghaish et al. [22], Mason [18], Sigalov et al. [45], and Rathnayake et al. [41]; however, none of these studies investigated these barriers profoundly.

Consequently, the in-depth literature review presented above shows that the existing studies do not provide any insight into the criticality of these barriers. Generally, they just provide a list of barriers and discuss them by assuming the same level of criticality. In addition, there is a limited number of studies using advanced techniques, such as FGD and fuzzy MCDM methods, to rank these barriers [24–26]. Thus, there is an evident need to investigate barriers to smart contracts based on these research gaps.

3. Research Methodology

To determine the most critical barriers to smart contract adoption in the construction industry, the following methodology, shown in Figure 1, was applied in this study. Following the review of the related works as given in Section 2, another literature review—whose details are given in Section 3.1—was conducted to extract the barriers proposed by the existing studies. Although blockchain and smart contracts have become popular in recent years, the number of studies about their barriers is limited. To verify the extracted barriers and determine barriers not revealed by existing studies, an FGD session was carried out with eleven well-experienced construction practitioners. Based on the FGD session findings, a questionnaire was prepared. Then, a survey was conducted with 15 professionals. The data obtained at the end of the survey was analyzed using fuzzy VIKOR, which is one of the most advanced MCDM methods.

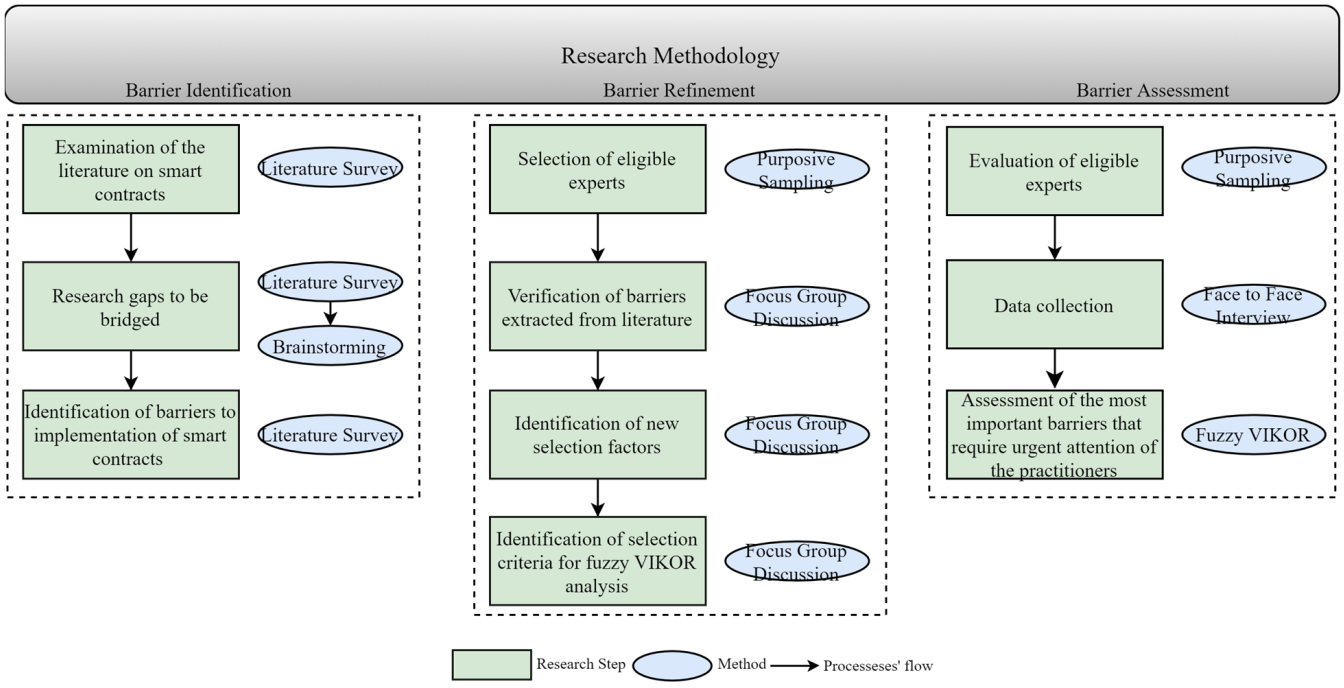


Figure 1. Research Methodology.

3.1. Literature Review

In the first step, a comprehensive literature review was conducted via the search engine Scopus to extract proposed barriers from the literature. Scopus was selected to ensure that only high-quality studies were considered in this study since Scopus is determined as superior to other search engines due to its popularity, scope, performance, and reliability [46]. The most significant superiority of Scopus is its wider scope. Mongeon and Paul-Hus [47] revealed that Scopus has coverage of 20,346 journals, while Web of Science has 13,605 journals. The study conducted by Falagas et al. [48] also verified these results. The study suggested that Scopus offers 20 percent more coverage than the Web of Science. The same study also concluded that Google Scholar suffers from inconsistent accuracy. Since this study focuses on barriers, smart contracts, and the construction industry, to determine the most relevant documents, TITLE-ABS-KEY ("smart contracts" AND "barriers" AND "Construction industry") search criterion was used. This criterion returned two papers. These two papers were examined, and one of them was eliminated since it does not propose any barrier to smart contract adoption in the construction industry. Since only one study was determined in the first search attempt, the search criterion was changed to identify more studies proposing barriers. ALL ("smart contracts" AND "barriers" AND "Construction industry") criterion was used in the second search. This search returned 70 studies. However, when these studies were examined, it was observed that most of them did not state the barriers to smart contracts. Therefore, another search was conducted with TITLE-ABS-KEY ("smart contracts" AND "barriers"). In this way, barriers proposed for other industries were also considered within the scope of this study. Finally, 89 studies were determined. To ensure fidelity and comprehensiveness, which are critical to paper quality assessment, a list of inclusion and exclusion criteria was defined [49]. Firstly, in this study, not only the articles published in prestigious journals were reviewed, but also the conference papers and reports, since there is a limited number of studies about barriers to smart contracts. Secondly, studies published between 2015 and 2021 were considered since the first platform, namely Ethereum, which supports general contract development, was released in 2015. Finally, all papers' abstracts were reviewed to determine their appropriateness. Based on all these evaluations, 14 studies were selected to identify barriers. By examining these studies, 20 barriers were identified. Table 1 shows these studies with their corresponding references.

Table 1. The extracted barriers.

Barriers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	FGD
Technology barriers															
Concerns over the storage capacity of the blockchain (TE1)	X	X	X												
Limited interoperability with building information modelling (BIM) and other platforms (TE2)	X							X						X	
Inability to eliminate human requirements in the process (TE3)								X							
Setup complexities and cost (TE4)												X	X		
Negative perception towards throughput bottlenecks (TE5)		X									X			X	
Negative perception towards scalability (TE6)		X	X		X					X	X	X			
Intra-organizational barriers															
Client's and/or contractor's concerns about giving entire control to an automated third party (IO1)								X						X	
Potential negative effects on stakeholders' relationship (IO2)												X	X	X	
Inflexibility to adapt to unforeseen conditions such as disputes (IO3)				X	X			X	X		X				
Uncertainty of the level of responsibilities of the parties in labor contracts (IO4)															X
Uncertainty of the party responsible for a problem to be encountered during and after the transaction in the blockchain system (IO5)															X
Complex dispute resolution process between contractor and subcontractor due to the involvement of employer (IO6)															X
Lack of competition due to the limited bargaining capabilities in the system (IO7)															X
Privacy and legal barriers															
Concerns over data loss due to immutability (PL1)		X									X	X			
Security concerns of practitioners (PL2)		X					X	X		X		X		X	
Lack of contract data privacy (PL3)	X	X		X	X	X	X				X	X	X	X	
Lack of trusted data privacy (PL4)	X	X		X	X	X	X					X	X	X	
Lack of legal infrastructure (PL5)		X	X								X		X	X	
Lack of appropriate regulations (PL6)												X	X	X	X

Table 1. *Cont.*

Barriers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	FGD
External barriers															
Lack of trusted link to the physical world (EX1)	X	X		X			X				X	X			
Lack of use cases and pilot implementations (EX2)								X							
Lack of financial subvention for smart contract technology (EX3)															X
Lack of government-backed initiatives (EX4)															X
Ambiguous attitude of the government towards smart contracts (EX6)															X
Inter-organizational barriers															
Lack of awareness of the organizations and top managers (IN1)								X		X		X	X		
Lack of knowledge and expertise to implement this technology (IN2)								X		X	X	X	X	X	
Unproven economic benefits (IN3)			X			X		X		X					
Uncertainties about how contract management will be performed (IN4)															X
Concerns that the new contract system will slow down production (IN5)															X

Note: 1—Li et al. [50], 2—Wang et al. [51], 3—Aloqaily et al. [52], 4—Grønbæk and Copenhagen [53], 5—Mohanta et al. [54], 6—Radhia et al. [55], 7—Singh et al. [37], 8—Mason and Escott [23], 9—McNamara and Sepasgozar [14], 10—Lamb [43], 11—Elghaish et al. [22], 12—Saberi et al. [56], 13—Lohmer and Lasch [57], 14—Etemadi et al. [58]. Bolted terms in the first column indicate barrier groups.

3.2. Focus Group Discussions

Although 20 barriers were identified from the literature, an FGD was conducted to verify the appropriateness of these barriers for the construction industry. FGD is an exploratory technique that has been widely used in the literature owing to its robustness and versatility [24]. In this method, data about a specific topic or issue is collected through negotiation and co-production of a small group of people led by a moderator (the researcher). Among other exploratory techniques such as structured and semi-structured interviews, FGD is perceived as a superior technique since it gathers and synthesizes data through dynamic and interactive group discussion [59]. Owing to this, FGD allows individual differences of opinion to arise while gaining insight into groups' shared understanding and beliefs [60]. Furthermore, continuous interactions between participants enable them to exchange and refine their ideas, experiences, and points of view [61]. Last but not least, FGD emerges as an ideal exploratory technique when there is the need to analyze the subject from various perspectives [62].

The important prerequisite of FGD is that the participants should have a similar background. In addition, FGD relies on participants' aptitude and capacity to contribute relevant information. Therefore, the selection of participants is critical for FGD to extract the most reliable findings [63]. In this study, purposive sampling, which is suggested for FGD [64], was used. However, purposive sampling is criticized due to researchers' bias unless their judgments are not based on clear criteria [65]. Therefore, a systematic expert selection procedure was developed. Accordingly, five criteria were proposed to identify eligible experts. To begin with, all participants should have a thorough understanding of how smart contracts are implemented, so even if they do not apply them, they have an idea of the barriers that will prevent them from being implemented successfully. Then, the participants' companies should be large since recent technology implementation requires high investment costs in terms of training and installment. Therefore, these companies are pioneers in the implementation of recent technologies and know the barriers to these technologies. The third criterion is the experience level of the participants' companies. According to this criterion, companies should have been in the construction industry for at least 10 years. Thirdly, the participants should have at least five years of experience in contract management. Fourthly, the experts should be working at either the client's company or the main contracting firms, so that both parties' perspectives can be captured. Lastly, experts are obliged to have at least a bachelor's degree. This criterion is essential for ensuring specialists have the necessary educational and theoretical backgrounds. It should also be noted that the experts were all selected from Turkish construction companies that have experience in the international market, such as Russia, the United Arab Emirates, Qatar, and Saudi Arabia. Based on the stated criteria, 16 experts were identified; however, only 11 of them agreed to participate in FGDs. Table 2 shows the demographic structure of these participants and their companies.

The appropriateness of the 11 participants for FGD was also evaluated based on the literature. There is no consensus on the appropriate FGD size. There are studies proposing that the FGD size should be between 6 and 10 participants to obtain a diversity of opinions while being small enough to avoid becoming disorganized or fractured [66]. They emphasized the problems of increasing the number of participants, especially since they stated that having more than 10 participants can make sessions complex and challenging to control. In addition, a small number of participants decreases the reliability of the results [63]. Consequently, the FGD size was determined to be appropriate for this study.

Table 2. The demographic structure of the participants and their companies.

ID	Size of the Company	Role	Experience of the Company in the Construction Industry (Years)	Experience of the Respondent in the Construction Industry (Years)	Experience of the Respondent in Contract Management (Years)	Knowledge of Smart Contract Implementation	Edu.	Organization
1	Large	Architect	21	10	6	Yes	BSc.	Client
2	Large	Project manager	21	16	6	Yes	BSc.	Client
3	Large	Architect	21	16	8	Yes	BSc.	Contractor
4	Large	Project manager	21	16	5	Yes	BSc.	Client
5	Large	Project manager	21	11	5	Yes	BSc.	Contractor
6	Large	Technical office chief	22	12	8	Yes	BSc.	Contractor
7	Large	Civil Engineer	22	11	5	Yes	BSc.	Contractor
8	Large	Architect	25	14	10	Yes	BSc.	Contractor
9	Large	Architect	26	17	5	Yes	MSc.	Client
10	Large	Consultant	25	16	10	Yes	BSc.	Client
11	Large	Project manager	22	13	5	Yes	BSc.	Client

Three FGD sessions were conducted under the supervision of one of the researchers to finalize the list of barriers. In the first session of FGD, the participants examined the identified barriers. Firstly, a list of extracted barriers was given to the participants. In this list, the participants evaluated these barriers by stating whether the proposed barrier is a barrier to smart contract implementation in the construction industry. In other words, participants evaluated the barriers without discussion. In this way, group conformity, which leads to criticism of the FGD method implementation [67], was eliminated. The forms were collected after all participants completed the evaluation procedure on their own. Then, the group discussion started by asking about the appropriateness of all the extracted barriers one by one; in other words, the participants discussed the appropriateness of each barrier. In the event that the participants could not reach a consensus about the validity of the barriers, the final decision was made based on the majority's opinions. Participants concluded that all barriers were valid at the end of these discussions.

In the second session of the FGD, participants were asked to add new barriers according to their experience. Participants proposed 11 new barriers at the end of the FGD. These barriers are the "Ambiguous attitude of the government towards smart contracts", "Lack of financial subvention for smart contract technology", "Complex dispute resolution process between contractor and subcontractor due to the involvement of employer", "Uncertainty of the party responsible for the problem to be encountered during and after the transaction in the blockchain system", "Lack of government-backed initiatives", "Inability to make bargains through the system", "Lack of competition in the system", "Uncertainties about how contract management will be performed", "Uncertainty of level of responsibilities of the parties in labor contracts", "Public demand for a high level of control", and "Concerns that new contract system will slow down production". The participants revised a list of 31 barriers at the end of the session. The participants agreed that barriers named "Inability to make bargains through the system" and "Lack of competition in the system" could be merged and named "Lack of competition due to the limited bargain capabilities in the system." Similarly, the participants proposed that "Regulatory uncertainty" and "Public demand for a high level of control" could be merged as "Lack of appropriate regulations." Based on the final revision, 29 barriers were proposed in this study. Table 1 shows these barriers.

The participants also grouped these barriers, and at the end of the second FGD session, they identified five groups by conducting a bottom-up approach. In this approach, the barriers were grouped based on their common properties. In addition, the participants named these groups. These groups are technology, intra-organizational, privacy and legal, external, and inter-organizational barriers. In the literature, similar groups for barriers were observed. For instance, Lohmer and Lasch [57] grouped the blockchain barriers into four groups, namely inter-organizational, intra-organizational, technology, and external barriers. The importance of legal barriers is also emphasized in the literature [35]. Therefore, the groups used in this study are also verified by the literature.

To assess the criticality of barriers, we should define the successful adoption of smart contracts. When a smart contract is adopted successfully, then it should help the successful completion of a construction project. Therefore, it is important to reveal how smart contracts affect the project's success which is generally measured using success criteria. In this study, the success criteria of construction projects that smart contracts might affect were identified by conducting an additional FGD session with the same participants. At the end of this session, the participants reached a consensus on three success criteria, namely time performance, cost performance, and organizational management performance. These criteria were considered as decision criteria for the research problem in the fuzzy VIKOR analysis.

3.3. Questionnaire Survey

After the identification of barriers, a questionnaire was prepared to assess the criticality of these barriers. The questionnaire consisted of three parts. The first part was about the

demographic structure of the participants. These questions provide an idea about the reliability of the obtained results. In the second part of the questionnaire, the respondents were asked to evaluate the impact level of the barriers on each success criterion based on seven linguistic variables shown in Table 3. In this study, fuzzy linguistic variables are used rather than numbers since experts can express themselves more clearly regarding the identified barriers. In this way, uncertainty is reduced [68]. The fuzzy membership function and fuzzy numbers are determined according to Lin et al. [69]. In the third part of the questionnaire, the respondents evaluated the success criteria based on the same linguistic variables.

Table 3. Linguistic variables and fuzzy numbers.

Linguistic Variables	Fuzzy Numbers	Linguistic Variables	Fuzzy Numbers
Extremely low	(0, 0.05, 0.15)	Fairly high	(0.5, 0.65, 0.8)
Low	(0.1, 0.2, 0.3)	High	(0.7, 0.8, 0.9)
Fairly low	(0.2, 0.35, 0.5)	Extremely high	(0.85, 0.95, 1)
Medium	(0.3, 0.5, 0.7)		

In this study, the barriers were evaluated following an MCDM perspective since these methods reflect the processes conducted by decision makers more realistically, which, in turn, may lead to more sound decisions [70]. There are many MCDM methods proposed in the literature such as the analytical hierarchy process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR). Among them, the VIKOR method was used in this study since it has several powerful features over other MCDM methods such as TOPSIS [71]. Firstly, VIKOR can fully reflect the experts' subjective preferences. On the other hand, the TOPSIS considers only group utility maximization and individual regret minimization [72]. Secondly, VIKOR can find a middle ground in a discrete decision-making dilemma with competing criteria. Finally, when decision makers are unable to choose or do not know how to choose the best options, the VIKOR method becomes the most useful tool. The VIKOR method is also redesigned by using fuzzy approaches and named fuzzy VIKOR to reflect the fuzzy environment where all decisions are taken [73]. Fuzzy set theory—which was proposed by Zadeh [74]—has proven benefits when it comes to maximizing the reliability and effectiveness of the MDCM methods [73]. Owing to the unprecedented benefits of fuzzy set theory, fuzzy VIKOR overperforms traditional VIKOR by effectively coping with inherent fuzziness and vagueness in expert judgements [73].

After selecting the appropriate analysis technique, the sample size, which is sufficient to obtain reliable results from this technique, should be revealed. The minimum sample size of MCDM methods is not determined by following strict rules since the sample size is a subjective and contextual measure. However, studies about MCDM acknowledge that these methods can be performed with a small sample size [75]. In addition, a large sample size can produce unrealistic findings due to cold-called respondents [76], especially for time-consuming questionnaires, since cold-called respondents are reluctant to spend their time on the questionnaires and can provide arbitrary answers. Furthermore, inconsistency in the findings can arise due to the large sample size [77]. Consequently, in the literature, many studies were conducted with a small sample size of ten or less experts. In this study, the sample size was aimed to be between 10 and 20 participants. In addition, to achieve the reliability of the fuzzy VIKOR analysis, the participants should have a high level of knowledge about the subject of the study. The population of this study is determined as Turkish experts who have experience in contract management, have knowledge of smart contracts and are working in large Turkish construction companies. Therefore, the same criteria used in the selection of the respondents who participated in FGD sessions were used in the selection of the respondents. By telephone, 20 experts satisfying these criteria were contacted. A total of 15 respondents, whose demographic structure is shown in Table 4, agreed to participate in the questionnaire survey. Survey return rate was 75%. Table 4

also shows that all participants are well experienced in contract management and highly knowledgeable about smart contracts, so the participants represent the population. All questionnaires were conducted face-to-face to avoid misunderstandings. In other words, immediate feedback was provided to the participants to clarify the questionnaire survey.

Table 4. The demographic structure of the respondents who participated in the questionnaire survey.

Role	Architect	Civil Eng.	Project Manager	Academic
	4	4	5	2
Size of the company	Small	Medium		Large
	0	1		14
Experience of the company in the construction industry (years)	0–10	10–20		20–30
	0	0		15
Experience of the respondent in the construction industry (years)	0–10	10–15		15–20
	0	9		6
Experience of the respondent in contract management (years)	0–5	5–10		10–15
	0	10		5
Education	BSc.	MSc.		PhD.
	10	2		3
Organization	Client	Contractor		Academy
	6	7		2
Knowledge level of smart contract	Low	Medium		High
	0	7		8

The collected data were analyzed using fuzzy VIKOR. To conduct the fuzzy VIKOR analysis, an Excel sheet was developed in-house by using the algorithm used by Opricovic [78]. The accuracy of the developed Excel sheet was tested by using the data and results provided by Sofiyabadi et al. [79]. The Excel sheet provided fuzzy numbers of S, R, and Q for each barrier and their corresponding crisp values. It should be noted that S and R stand for maximum group utility and minimum individual regret while Q is calculated by both evaluating S and R values. Then, barriers were ranked by sorting crisp Q values in descending order. In other words, a barrier with the smallest crisp Q value is determined as the most important barrier. The following tables show the top ten and bottom five barriers and their corresponding crisp S, R, and Q values.

4. Discussion of the Findings

The results of the FGD sessions verified that smart contract implementation has diverse barriers related to various aspects of projects, technologies, and organizations. In other words, smart contract implementation requires comprehensive evaluation rather than focusing solely on a single perspective. Rahman [29] also mentioned the need for an integrated and holistic strategy for innovative technologies adoption. "Technology" was identified as the first aspect of the barriers. This aspect focuses on the barriers arising from technical and technological complexities of smart contracts and blockchain systems. The main concern of the participants is mainly because smart contracts and blockchain are highly disruptive technologies [80]. So, it is very likely to encounter unprecedented challenges during their actual implementation. The second aspect of the barriers was identified as intra-organizational. Smart contracts have significant potential to change the financial and managerial relations of the parties involved in a construction project. Given that construction companies already have complicated and turbulent relationships [4,5], potential smart contract deployment to construction projects triggers considerable uncertainty in terms of intra-organizational relationships. Next, the privacy and legal aspects of smart contracts comprise a significant number of barriers. Traditionally, construction businesses are run with stakeholders having different and secret agendas. Smart contracts are seen as a serious disruption to this mechanism since the blockchain system offers transparency. Fourthly, smart contracts' connection with the external environment also presents some

degree of uncertainty. Thus, participants are worried about how the system will be connected to governments' financial and legal systems. Last but not least, inter-organizational aspects of the barriers were additionally identified by the experts, and they stated barriers related to the inter-organizational mechanisms of construction companies. In particular, both employees and employers tend to resist disruptive changes, since they tend to follow traditional management practices [80]. Thus, decision makers as well as academics should be aware that they should focus on all aspects of smart contract adoption.

The criticality ranks of the identified barriers also provide valuable insight. The most critical barriers are IO7, TE5, IN2, IN5, and IN4 according to Table 5. Participants in the FGD session proposed three of these five critical barriers. In other words, this study reveals some critical barriers that existing studies overlook. This shows that the adoption process of smart contracts differs from the adoption process in other industries, such as manufacturing and services. This can be explained by considering innovation's context sensitive nature [27]. Due to the project-based nature of the construction industry, it has servicing and manufacturing features; therefore, the construction industry has a unique structure, which in turn may lead to unique barriers to change [30]. Consequently, the studies on innovative solutions, such as smart contracts, are necessary for the construction industry to implement these solutions effectively.

Table 5. Ranks of the barriers and their corresponding S, R, and Q values.

Barriers	Sg	Rg	Qg	Ranks
Lack of competition due to the limited bargain capabilities in the system (IO7)	0.612	0.269	0.028	1
Negative perception towards throughput bottlenecks (TE5)	0.542	0.293	0.030	2
Lack of knowledge and expertise to implement this technology (IN2)	0.582	0.293	0.036	3
Concerns that the new contract system will slow down production (IN5)	0.685	0.295	0.050	4
Uncertainties about how contract management will be performed (IN4)	0.660	0.305	0.052	5
Complex dispute resolution process between contractor and subcontractor due to the involvement of employer (IO6)	0.683	0.303	0.054	6
Client's and/or contractor's concerns about giving entire control to an automated third party (IO1)	0.764	0.311	0.068	7
Uncertainty of level of responsibilities of the parties in labor contracts (IO4)	0.696	0.334	0.070	8
Uncertainty of the party responsible for the problem to be encountered during and after the transaction in the blockchain system (IO5)	0.679	0.347	0.073	9
Ambiguous attitude of the government towards smart contracts (EX6)	0.758	0.329	0.076	10
Lack of legal infrastructure (PL5)	0.763	0.342	0.082	11
Inflexibility to adapt unforeseen conditions such as disputes (IO3)	0.785	0.339	0.084	12
Lack of use cases and pilot implementations (EX2)	0.767	0.345	0.084	13
Limited interoperability with building information modelling (BIM) and other platforms (TE2)	0.819	0.331	0.085	14
Lack of appropriate regulations (PL6)	0.797	0.350	0.091	15
Setup complexities and cost (TE4)	0.838	0.340	0.092	16
Lack of trusted data privacy (PL4)	0.800	0.365	0.098	17
Lack of awareness of the organizations and top managers (IN1)	0.817	0.363	0.099	18
Negative perception towards scalability (TE6)	0.862	0.355	0.102	19
Lack of contract data privacy (PL3)	0.832	0.368	0.104	20
Lack of financial subvention for smart contract technology (EX3)	0.893	0.353	0.105	21
Concerns over data loss due to immutability (PL1)	0.923	0.355	0.110	22
Lack of trusted link to the physical world (EX1)	0.942	0.365	0.118	23
Inability to eliminate human requirements in the process (TE3)	0.962	0.368	0.121	24
Lack of government backed initiatives (EX4)	0.927	0.404	0.133	25
Security concerns of practitioners (PL2)	0.995	0.400	0.140	26
Potential negative effects on stakeholders' relationship (IO2)	1.089	0.410	0.158	27
Concerns over the storage capacity of the blockchain (TE1)	1.074	0.423	0.162	28
Unproven economic benefits (IN3)	1.166	0.450	0.187	29

Among these five critical barriers, only one of them is related to the technological aspect of smart contract adoption. Therefore, the respondents believe that smart contract adoption is not a technological implementation. In particular, inter-organizational barriers are determined as more critical since three of the most critical barriers are inter-organizational barriers. Therefore, the construction companies should start with their organizations when they are adopting a smart contract. The main reason for having critical inter-organizational barriers can be resistance to change, since resistance to change is a widely seen barrier to innovation in the construction industry due to the traditional and conservative structure of the construction industry [30,81]. In addition, since smart contracts have the potential to lead substantial changes in smart contract adoption, resistance to change is widely considered [15]. For instance, Koutsogiannis and Berntsen [82] asserted that one of the important barriers to the blockchain adoption in construction companies is organizational resistance. Ahmed [83] proposed that organizational resistance at both the employee and middle management levels can considerably hinder the adoption of building information modeling. Similarly, Gurgun and Koc [21] determined cultural resistance as one of the administrative risks of smart contract implementation in the construction industry. Van Wyk [31] observed that the employees are eager for innovation. However, they have concerns about losing their jobs, since they do not have the required skills and knowledge about these new technologies. Therefore, employees perceive the changes due to smart contract implementation as a threat due to their career concerns [83]. According to Adafin [84], internal employee training can overcome organizational resistance to innovation. Therefore, to overcome change resistance, top management should provide proper training, education, and support to their employees [15]. In this way, the employees can adopt the changes without an extra labor burden, which in turn can lead to a tendency to change [85].

The other critical barrier is related to changes in the relationships between the other parties, since according to Table 5, five of the top ten barriers are related to inter-organizational barriers. The smart contract adoption also affects the relationships between the parties, especially the transparency which is one of the most important smart contract features. However, in the construction industry, lack of trust is an important problem, therefore, the collaboration between the parties is low. Whereas, smart contract systems require trust, collaboration, and confidence among project stakeholders [15,23]. Therefore, to adopt the smart contracts, companies should change their procurement mindsets and strategies [23]. In addition, according to Gurgun and Koc [21], the mindset of the construction industry leads to administrative risks in smart contract implementation. In other words, the existing competitive mindset in construction projects should transform into a collaborative mindset to adopt smart contracts effectively.

The most important barrier was a change in bargaining power. Smart contracts are considered the panacea for unequal bargaining power in business transactions [86]. However, in construction projects, the parties have different bargaining powers, and the more powerful parties use this power to delay their payments and prefer using these payments as a way to bargain [17,87]. Respondents believe they will lose bargaining power with smart contracts. As a result, losing bargaining power through smart contract adoption prevents companies from investing in smart contracts. This shows that smart contracts cannot be adopted in the construction industry, which is highly fragmented and characterized by adversarial relationships. Therefore, the first step should be a change in the mindset of the construction industry.

TE5 was rated as another significant critical barrier. The explanation lies in the fact that construction projects recently became complex and sophisticated projects [88]. Given that complexity maximizes the number of stakeholders, commercial relationships, and potential conflicts, the scalability of technology became a significant point of concern for practitioners. Khan et al. [40] also mentioned about the performance problems of smart contracts due to scalability and throughput bottleneck. However, they mentioned that there are new solutions proposed in the literature. Additionally, construction projects

are investment-intensive projects so project stakeholders have no tolerance for delays in the payments due to bottlenecks that could occur in the smart contract system [4]. Thus, there exists a significant negative perception towards throughput bottlenecks of the smart contracts among the participants since the scalability of the system has not been tested and verified in the engineering practice, yet [89].

This study also shows that "lack of knowledge and expertise to implement this technology" is one of the most critical barriers. Since the smart contract is a new concept and has a unique infrastructure, there is a limited number of suitably skilled information technology personnel on the market [50]. In addition, developers may also lack contractual knowledge and operational technology, causing them to overlook key parts of traditional contracts, such as obligations, rights, and contract restrictions [90]. To overcome this barrier, companies should provide appropriate training to their staff [57]. Furthermore, to fill the gap between operational technology and information technology, Zheng et al. [91] proposed that natural language processing and artificial intelligence technologies could be integrated into the smart contract development process.

The respondents also have concerns about giving all authority to the automated third party since understanding all processes performed by the smart contracts is a challenging process due to the codes used in the preparation of smart contracts and blockchains where smart contracts are deployed [91]. In addition, smart contracts cannot be modified after being deployed so the parties cannot exploit the traditional contracts' flexibility and their judgment. Mason [18] proposed semi-automation in the adoption of intelligent contracts to overcome these challenges. Therefore, the parties do not give all control to the third party, and they can still benefit from the automation of certain processes. Due to the complexity of the construction projects and the lack of legal precedents and regulations, semi-automation can be considered a feasible solution for overcoming this barrier. However, with the increasing maturity of smart contracts, fully automated smart contracts can also become more feasible to eliminate all disputes.

This study suggests that the respondents acknowledge the benefits of smart contracts since the least critical barrier is determined as unproven economic benefits according to Table 5. In addition, they consider that the awareness level of the organizations and top managers is not a critical barrier for smart contract implementation. This facilitates smart contract adoption since the companies can boost the smart contract implementation by showing the drivers and benefits of successful smart contract implementations to their employees [21]. Similarly, Li et al. [50] also emphasized the importance of smart contract benefits to mitigate further adoption resistance risks. Although they are aware of the benefits of smart contracts, they have concerns about the direct and indirect costs of smart contract implementation. Therefore, a cost–benefit analysis can help companies make informed decisions about the adoption of smart contracts.

Overall, the results shown in Tables 1 and 5 make significant contributions to engineering practice. This study proposes a framework that will provide guidance to decision makers in identifying solutions to critical barriers. In this way, financial and non-financial resources could be efficiently utilized before and during smart contracts implementation. Furthermore, in addition to practitioners, the proposed framework presents promising benefits for researchers. By developing a comprehensive framework showing the barriers to smart contracts implementation, it is highly believed that the outcomes derived from this study will shed light on future studies that aim to maximize smart contracts effectiveness. In addition, this research involves a versatile and robust methodology that uses fuzzy set theory and an MCDM method [25,26], making it easy for the technique to be replicated for a variety of innovative technologies and/or industries.

5. Conclusions and Recommendations

Due to the problems of traditional contracts, automated contract administration has been proposed in the literature and smart contracts have become popular in recent years. However, smart contract implementation has not been at the desired level in the construc-

tion industry. In addition, since the maturity of smart contracts is low, the companies have limited information about how to adopt smart contracts. Therefore, smart contracts should be investigated to increase their applicability in all aspects. However, the barriers to smart contract adoption in the construction industry have not been investigated comprehensively in the literature, even though identifying the implementation barriers of new technologies is of paramount importance [58,83]. However, by developing initiative-taking solutions and strategies to overcome these barriers, companies can maximize the effectiveness of smart contracts.

In this study, 39 barriers were identified as a result of the literature survey and FGDs. Nine of these barriers were revealed at the end of the FGDs, in other words, some barriers were identified specifically for the construction industry. Identification of these barriers is critical for companies since due to the distinct characteristics of each industry, these barriers cannot be revealed in the studies conducted for different industries. The criticalities of these barriers were examined using fuzzy VIKOR to reveal the top barriers, thus the companies can allocate their limited resources more effectively. According to the findings of this study, the most critical barriers are not the barriers that were extracted from the literature. Contrarily, the barriers proposed in FGD sessions were rated as the most critical by the experts. Therefore, more efforts should be devoted to identifying and assessing the barriers to smart contract adoption by considering the distinctive conditions of industries and/or countries.

The findings highlighted that stakeholders have concerns about changes to traditional processes. They especially do not want to lose their bargaining power. However, in the long run, relying on bargaining power can lead to disputes between parties. Therefore, the construction industry's mindset should be changed from competitive to collaborative to adopt smart contracts. Such a mindset change could only be achieved with the collaboration of NGOs and government institutions. Given that the implementation of smart contracts is a facilitator for increasing collaboration between parties, NGOs together with government institutions should promote the effectiveness of smart contracts when it comes to avoiding disputes between contracting parties. Secondly, government institutions could oblige construction companies to implement smart contracts in state-owned construction projects. These projects could provide a convenient medium to test smart contracts' effectiveness. In this way, stakeholders become convinced of the smart contracts' benefits. Still, it should be noted that intra-organizational barriers are also considered critical, therefore organizations should focus on the relationships with the parties before applying smart contracts.

This study also shows that participants have limited concerns about the technical aspects of smart contracts. Most of the critical barriers are related to managerial aspects of smart contracts. Due to the immaturity of smart contracts, there are many uncertainties, so companies cannot predict what they will encounter in smart contract implementation. Consequently, smart contract administration should also be investigated in all aspects to provide insights for managers. The adoption of smart contracts in the construction industry can be effectively achieved. Smart contract implementation in construction should automate all payments. Accordingly, the deployed smart contract manages all payments to the contractor and/or subcontractors based on the work carried out on site. In this respect, all payments are completed on time and with transparency. Before the actual deployment of the smart contract system, construction companies are recommended to first implement smart contracts in pilot projects. After that, they will be fully deployed to larger projects. In this respect, the know-how required to implement smart contracts in large-scale construction projects could be obtained.

Like other studies, this study also has some limitations which can be considered by future studies. The limitation of this study is the lack of validation of results. Performing a validation by conducting a case study can be an important contribution to the literature. This is one of the pioneer studies related to the adoption of smart contracts in construction management. This study can provide insights into construction companies. In addition,

the identified barriers can be used by studies to reveal the interrelationship between the barriers to developing roadmaps for effective smart contract implementation.

Last but not least, although this study presents an in-depth review of the smart contract literature, scientometric analysis of existing studies was not conducted within the scope of this study. Given the fact that scientometric analysis using different software, such as Vosviewer, could provide significant knowledge of the smart contract literature, the issue could be addressed in future studies.

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