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Operational Barriers against the Use of Smart Contracts in Construction Projects

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ABSTRACT

As an emerging but embryonic way of contract administration, smart contracts can play a prominent role in managing construction projects in an effective manner. However, there are still some barriers preventing the implementation of them in the life cycles of construction projects. This study investigates operational barriers against the adoption of smart contracts in construction projects and explores the challenges in this process. Operational barriers against smart contract implementation are identified through a comprehensive literature review and a focus group discussion is performed to refine the identified barriers. These barriers are evaluated through fuzzy analytical hierarchy process analysis. Finally, a framework is proposed for the adoption of smart contracts effectively in construction projects. 20 operational barriers were attained based on four main barrier categories: technical, financial, security/technological, and time. The results show that financial and technical aspects establish the most significant categories hindering the adoption of smart contracts, while expensive and clunky drafting and registration process, and cost of upskilling are the most significant barriers. Overall, the proposed framework might be useful for practitioners and project managers, who decide to use smart contracts in managing construction projects. The motive behind understanding critical operational barriers is to assist construction practitioners in automating contract execution processes. This study provides a basis for recommending the necessary strategies for the use of smart contracts in the industry to researchers in the construction management field.

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1. INTRODUCTION

Many construction projects are complicated, large-scale, long-lasting, and characterized by a higher level of uncertainties. Therefore, strategic decisions require the involvement of project stakeholders to manage construction projects effectively [1]–[3]. These features make it more difficult to achieve project objectives in the context of planning, management, and contract administration. Therefore, project managers and construction professionals are in search of robust project management tools and managerial support techniques [4]. Integrating various methods and technologies to have profitable outcomes is a must in construction projects [5], performance of which rely on different dimensions of project management [6]. In this vein, management of construction projects has gradually encompassed a broad range of elements related to sustainable project governance [1], with contract management playing a central role [7]. Forestalling all adversities and uncertainties and including them in contract management with the participation of project stakeholders become a difficult task [8], threatening the recovery from or adjustment to setbacks or changes in construction projects. These unprecedented drawbacks may lead to productivity loss, payment problems, delays, cost overruns, and inevitably project disputes [9].

Mutikanga et al. [10] pointed out that many contractual issues exist in engineering, procurement, and construction projects, such as insufficient project scope and goals, and poor compliance with contractual obligations by project parties. McKinsey Global Institute [11] highlights that misalignment of the structure of contract documents is one of the major causes of low productivity in construction projects. A recent report by Arcadis [3] underlined that poorly drafted documents, errors and/or omissions in contracts, and liabilities misunderstood by clients, contractors or sub-contractors were the top causes of disputes in construction projects. Due to the inherent incompleteness of construction contracts [12], organizations that use traditional contracts may face many setbacks hindering effective management of iron triangle (i.e., time, cost, and quality) [13]. To deal with these challenges, smart contracts are one of the technological tools that are developed through distributed ledger technology and offer great potential for many industries including the construction industry [14]. Smart contracts leading to innovative solutions have drawn considerable attention in various industries, including education, energy, healthcare, banking, and financial services, public management, construction, supply chain, and entertainment [15], [16]. Compared with other industries, the development and implementation of smart contracts in the construction industry can be relatively slow and challenging due to their complex, unique, and dynamic characteristics.

The dominance of digital age on global commerce portends that smart contracts could have a prominent place in the future business environment [17] since the underlying blockchain technology is practical in many ways and able to provide a mechanism that is more secure than traditional contracts [18]. Many aspects of the requirements, terms, and clauses of a contract can be managed technologically by smart contracts [19]. This would not only support the coordination of several contract administration processes but also organize the payments through improved payment pipeline in construction projects, where late payments are inherent culture [20]. By considering the traceability, security, and immutability of the blockchain technology, blockchain-enabled smart contracts also contribute to elevating the confidence level of the stakeholders [21]. On the other hand, smart contracts can be used as an effective tool in resolving or reducing conflicts/disputes among parties included [22]. Improved transparency through transaction credibility, efficiency, intelligence, and automation can also be an additional advantage in several processes. However, some issues such as the initial investment cost or the inefficiency of the consensus mechanism can still be considered as major inhibitors against their application [23]. Similarly, lack of qualified human resource or capabilities of organizations regarding smart contracts may also pose an obstacle for stakeholders desiring to rely on smart contracts.

The efficiency of smart contracts and their ability to overcome a number of current challenges in traditional contracts put them in a place that could take over traditional contracts [24]. However, many research in the literature highlighted the significant operational challenges that might limit the adoption of smart contracts in construction projects [14], [22]. This study aims to have a deeper understanding on smart contracts by evaluating operational barriers and developing a conceptual model for construction companies to adopt smart contracts with the guidance of the findings. A multi-step framework has been followed to achieve the study objective. First, a comprehensive literature review and focus group discussion (FGD) were performed to identify challenges against smart contract adoption. Then, fuzzy analytical hierarchy process (AHP) was used to evaluate identified barriers. Finally, a conceptual smart contract adoption framework was developed based on the analysis results. The findings of the analysis steps make several contributions to the current literature on smart contract, contract administration, and project management by proposing a way to operate smart contracts in construction projects. With the study findings, construction projects can be better managed with smart contracts by eliminating risks of adopting them since contract life-cycle management requires more robust and automated processes in today's competitive environment. Besides, construction managers can use the results of this study in terms of minimizing inefficient paper-based procedures, dealing with conflicts through analytical methods, preventing unexpected cost increases, and preserving privacy of contracts. Overall, the outcomes of this study are expected to raise awareness among construction industry practitioners and develop improved risk mitigation strategies based on the contract life cycle of construction projects.

2. BACKGROUND

2.1. Definition and Role of Smart Contracts

In 1994, an American computer scientist, lawyer, and cryptographer, Nick Szabo [25], coined the term smart contract. Szabo [26] defined smart contract as a computer-based transition protocol executing the clauses of a contract. Fundamentally, smart contracts are designed to meet or fulfil common contractual requirements and abate accidental or malicious peculiarities. These contracts are primarily characterized by their digital forms and are embedded in hardware and software as code [27]. Rule-based operations and the underlying blockchain technology enable the release of payments securely, fulfil the contract terms visibly, and thereby reduce contractual conflicts. Smart contracts are expected to have a vast effect on contract law and the economy with more efficiency, traceability, and confidentiality, which are little explored [28]. Containing electronic clauses and triggering processes according to the terms of the contract, a smart contract is a self-executing contract and works depending upon automated conditional performance management. Smart contracts work in a way to allow the triggering of an obligation, once the task associated with the obligation is fulfilled [29]. For example, the ownership of real assets can be digitally controlled with smart contracts based on the terms of the agreement and these contracts provide stakeholders with clear information management systems.

Smart contracts are written as codes in both hardware and software [30], and accessed through an agreed data source unlike traditional contracts that are written in legalese language [31]. The blockchain technology keeps the identical and dynamic copies of the contract and included parties can check the amendments according to a consensus algorithm. Therefore, comparison software is needed for the verification of documents to avoid or prevent unapproved contract term changes made by other parties in blockchain-enabled smart contracts [32]. The status of the contracts can be viewed optionally and dynamically, and monitored by the project stakeholders, which allows them to adjust to the changing conditions. Blockchain technology is the stepping stone of smart contracts. Therefore, a secure blockchain and coding are essential. All these requirements are usually considered as barriers for construction companies, limiting the investments in blockchain technology and adoption of smart contracts in their business operations.

2.2. Studies about Smart Contracts in the Construction Industry

Smart contracts can be regarded as a prominent tool of self-executing digital transformation initiatives by coding contract terms and conditions that reduce cost and time overruns, while addressing contractual risks and disputes during contract management life-cycle [22]. Smart contracts can add significant value to the construction projects with their ability to decentralize the execution of contract requirements [33]. Existing literature mostly highlights their impacts on the security, traceability, and automation in the process of construction projects. For instance, Bolhassan et al. [22] investigated various benefits and implementation challenges in the Malaysian construction industry. The study suggested the use of smart contracts in short-term projects. Chong and Diamantopoulos [34] performed a case study to automate the payment process for façade panel supply by incorporating several advanced technologies such as smart contracts, smart sensors, BIM, and blockchain. Mason and Escott [35] investigated the stakeholder perceptions of smart contracts in the construction industry and highlighted their fear about the full automation in contract administration. Similarly, Nanayakkara et al. [36] conducted a workshop with six groups to exhibit stakeholder perceptions of smart contracts for construction supply chains and found that stakeholders mostly addressed efficiency, trust, fairness, security, transparency, accountability, compliance, and standardization features of smart contract-based solutions. Li and Kassem [37] employed a systematic review analysis and stated that smart contracts as supplementary technologies can be used with other technological systems, which were still immature to be used with smart contracts. Li et al. [38] developed a model that integrated smart contracts with BIM, IoT, and DLT to automate installation activities in construction and addressed that the proposed approach could minimize several challenges such as late payments, lack of trust, and inadequate collaboration.

In another study, Rathnayake et al. [39] conducted a systematic literature review and highlighted that past studies usually focused on drivers, barriers, implications, and benefits affecting the adoption smart contracts in the construction industry. They found that lack of security, lack of observability, incompatibility, inactive government collaboration and storage capacity restrictions were the most frequently identified barriers in smart contract implementation. Similarly, Shang et al. [40] concentrated on institutional factors influencing the adoption of smart contracts in the Singapore construction industry. The researchers also underlined the barriers of poor knowledge of smart contracts, lack of industry-specific standards, and lack of observability. Ameyaw et al. [41], using statistical analyses, investigated the drivers for blockchain-based smart contracts applications in construction projects. Considering the opinions of experts in the field, the researchers specified trialability of smart contract (such as ability to try, and a trial period before adoption), transparency in project delivery, facilitation in payments, and security of payment as the top critical factors. Gurgun and Koc [42] presented a multi-criteria approach to identify and evaluate administrative risks of the smart contracts based on contractual, cultural, managerial, planning, and relational main risk groups. The researchers emphasized the necessity of handling the managerial risks diligently to increase the adoption of smart contracts in the projects.

Various studies also proposed solutions using smart contracts regarding payment issues, which is one of the challenges inherent in construction projects. For instance, Hamledari and Fischer [33] examined their effects on enhancing visibility of payments in the supply chain and stated that although smart contracts cannot fully ensure information latency yet, they are effective instruments for information completeness. Ahmadisheykhsarmast and Sonmez [43] presented a smart contract-based payment security system to minimize payment problems (i.e., non-payment and/or late payment) by using the schedule and cost data. Similarly, Luo et al. [44] proposed a smart contract-based interim payment management framework to automate the process in a blockchain environment. The comprehensive literature review illustrates that operational barriers against the adoption of smart contracts have not been researched systematically, which formed the research motivation of this study.

3. METHODOLOGY

The steps of the study are illustrated in Figure 1 and each step is explained in the following sub-sections.

3.1. Literature Review

In the first step of the study, a comprehensive literature survey was performed to identify initial list of operational barriers against smart contract implementation in construction projects. For this purpose, search engine Scopus was used to gather relevant research articles since it is one of the widely used search tools in nearly any domain and shows an effective performance compared to other search engines [45]–[47]. As a preliminary search step, two main search strings were considered as (i) “Smart contract” AND (ii) “Risk OR “Barrier” OR “Challenge”. This search retrieved 809 publications, which was reduced to 336 articles by limiting the results with only journal papers. Then, another search string i.e., "Construction" was inserted, and the number of studies was reduced to 24 that are directly related to the construction industry. Hence, 24 articles were investigated in detail, while the remaining 312 articles were examined on an abstract level. The reference list of 24 articles was also explored as part of snow-balling approach in order not to exclude any of the relevant past research. Accordingly, the initial list of operational barriers was ensured mainly based on the studies of Mason [48], Mason and Escott [35], Li et al. [14], Perera et al. [49], and Gurgun and Koc [42].

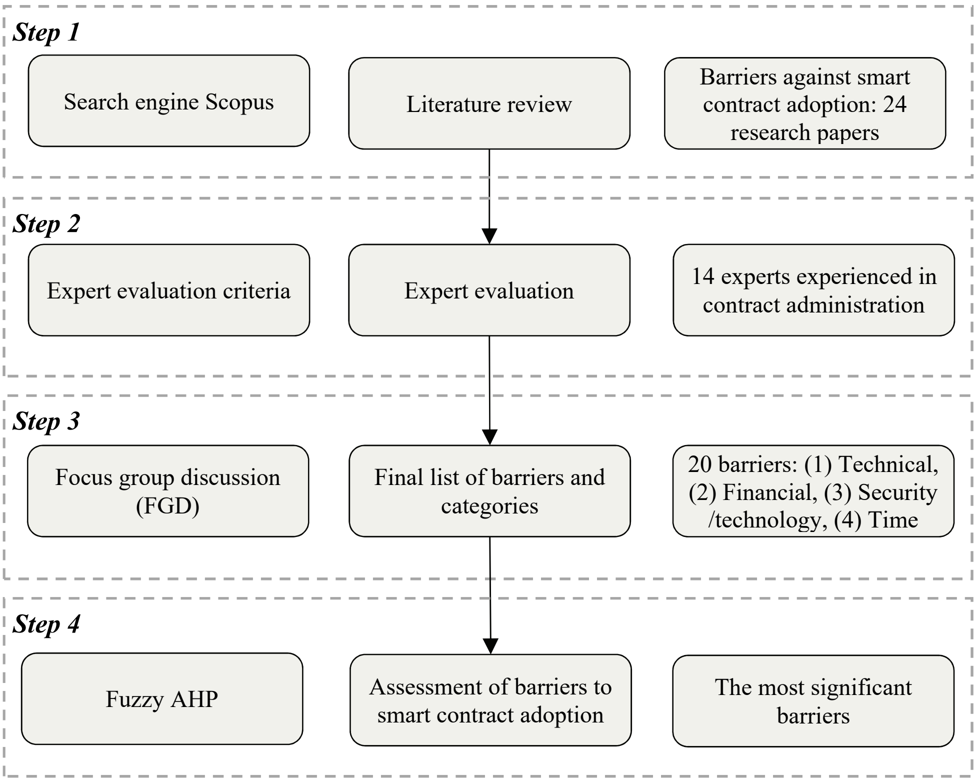

Figure 1 - Research flow.

3.2. Expert Evaluation

This study adopted two consecutive steps to analyze the identified operational barriers. In the first step, a focus group discussion (FGD) was employed with industry professionals to finalize the decision framework. It was organized before the data analysis since including expert opinions to construct decision framework is an effective approach [50], [51]. This step was followed by a fuzzy AHP analysis to prioritize the operational barriers. Both steps (FGD and fuzzy AHP) are based on expert knowledge, thus evaluating the eligibility of experts becomes a critical concern of this study. First, the required sample size for FGD and fuzzy AHP was identified through a literature survey. Accordingly, 5 and 9 experts were determined to be adequate sample size for FGD [47], [52], [53] and fuzzy AHP [42], [54]–[56] analyses, respectively. The major reasons to perform FGD sessions with 5 experts can be summarized as follows: too many focus group participants may cause the session complexity (e.g., between 10 and 20) [57], and few participants might hinder sharing critical and creative opinions (e.g. <5) [50], [58]. Similar to FGD sessions, more efficient data collection can be realized and reliable results can be generated in AHP or fuzzy AHP applications with small sample sizes [50]. The method may even result in unassured criteria weights owing to the tendency of “cold-called” participants to provide random preferences as the sample size is increased [59]. Hence, data quality is signified in AHP applications compared to data quantity [60]. Furthermore, the AHP method is usually preferred by researchers due to its suitability for dealing with sample size limitations [59].

All the participants attended to this study were carefully examined based on the following criteria: (i) having at least 5-year experience in contract administration in the construction industry, (ii) having at least BSc degree in civil engineering or architecture programs, (iii) having a managerial experience in at least 2 construction projects. After contacting 14 experts, 9 and 5 of them showed their willingness to participate in this study in fuzzy AHP and FGD steps, respectively. Participants had diverse backgrounds (Table 1) and are currently working in Turkey. Table 1 shows the contribution of the participants, their positions in the organizations, organization type, and experience in the construction industry.

Table 1 - Profile of participants.

Expert ID	Contribution	Position in the organization	Organization type	Experience
Expert 1	Fuzzy AHP	Tendering engineer	Private client	11
Expert 2	Fuzzy AHP	Site chief	Private contractor	16
Expert 3	Fuzzy AHP	Cofounder	Private contractor	34
Expert 4	Fuzzy AHP	Technical office engineer	Private consultant to client	8
Expert 5	Fuzzy AHP	Design manager	Private consultant to client	14
Expert 6	Fuzzy AHP	Senior executive director	Public client	41
Expert 7	Fuzzy AHP	Procurement manager	Private contractor	12
Expert 8	Fuzzy AHP	Contract manager	Public client	18
Expert 9	Fuzzy AHP	Cost control manager	Public client	29
Expert 10	FGD	Design architect	Private contractor	9
Expert 11	FGD	Planning and cost control manager	Public client	17
Expert 12	FGD	Owner	Private sub-contractor	33
Expert 13	FGD	Interim payment engineer	Private contractor	12
Expert 14	FGD	Director	Private consultant to client	24

3.3. Focus Group Discussion (FGD)

FGD is an exploratory discussion technique that has been extensively used in research studies to collect expert opinions [47], [61] and is particularly convenient for exploring the diverse perspectives of participants with similar backgrounds, opinions, or experiences on a research topic [62], [63]. Gold and Vassell [61] highlighted the advantages of focus groups such as time-effective and cost-effective. They can also generate satisfactory output with the involvement of 5 to 10 participants [62]. Yu and Leung [64] addressed that 4 to 6 participants constituted mini focus groups and 7 to 10 participants constituted small focus groups. The reason to adopt the FGD technique in this research was to obtain the expert opinions that have the required level of experience in contract management and administration to identify the operational barriers against the adoption of smart contracts and develop a framework that would facilitate their adoption in construction projects. Based on the results of FGDs with 5 experts, the selected operational barriers are illustrated in Table 2.

Table 2 - Operational barriers to smart contract adoption.

Barrier category	Barrier ID	Barrier	Reference
Technical (Tc)	Tc1	Lack of experienced personnel	Etemadi et al. [65]
	Tc2	Complexity in draft development	Etemadi et al. [65]
	Tc3	Irrevocable nature of smart contracts	Li et al. [14]
	Tc4	Updating issues after changes	Yamashita et al. [66]
	Tc5	Inaccurate recorded information	Li et al. [14]
	Tc6	Incorrect coding and interoperability issues	Wong et al. [67]
Financial (Fn)	Fn1	Expensive and clunky drafting and registration process	Gurgun and Koc [42]
	Fn2	Cost of upskilling	Mason and Escott [35]
	Fn3	Cost of updates required frequently	Li et al. [14]
	Fn4	Cost of adequate human resource	Meier and Sannajust [8]
Security/ Technological (St)	St1	Bug probability leading to permanent failure	Mason and Escott [35]
	St2	Privacy issues in terms of information security	Deebak and AL-Turjman [68]
	St3	Possible cyber-attacks/security risks	Zhao et al. [69]
	St4	Lack of technological advancements in the company	Wong et al. [67]
	St5	Error prone nature of transactions in smart contracts	Wong et al. [67]
Time (Tm)	Tm1	Requirement of excessive time for approval procedures in construction	Perera et al. [49]
	Tm2	Difficulty in setting deadlines and original time scales	Mason [48]
	Tm3	Time constraints (such as insurance arrangements etc.)	Mason [48]
	Tm4	Time consuming process of developing the contract draft	Li et al. [14]
	Tm5	Long lasting negotiation process in construction	Mason and Escott [35]

3.4. Fuzzy Analytical Hierarchy Process

The AHP method is one of the most widely used multi-criteria decision making (MCDM) methods in the literature [70]–[72], mostly due to its simplicity regarding hierarchical representation and the understanding of mathematical calculations. However, uncertainty about expressing the decision maker's decisions with exact numbers is a critical concern in most of the MCDM methods. To overcome this difficulty, the fuzzy AHP method was developed to address the fuzziness of decision makers [70]. In this method, fuzzy set theory proposed by Zadeh [73] was incorporated into AHP method by Chang [74], which is called extent analysis. Since then, it has widely been used in the literature and adopted in this study. There are four steps in the employment of the fuzzy AHP analysis:

Step 1. Data collection: Linguistic variables were used by experts to indicate the importance of barriers by means of pairwise comparisons. Triangular fuzzy scale for linguistic variables that are adopted in the current study is given in Table 3 [70], [75].

Table 3 - Triangular fuzzy scales.

	AHP		Fuzzy AHP	
Linguistic variables	Importa nce	Value for reciprocals	Triangular fuzzy numbers (l_{ij},m_{ij}, u_{ij})	Triangular fuzzy reciprocals (1/u_{ij}, 1/m_{ij} , 1/l_{ij})
Equally important	1	(1/1)	(1, 1, 1)	(1, 1, 1)
Intermediate value	2	(1/2)	(1, 2, 3)	(1/3, 1/2, 1)
Moderately important	3	(1/3)	(2, 3, 4)	(1/4, 1/3, 1/2)
Intermediate value	4	(1/4)	(3, 4, 5)	(1/5, 1/4, 1/3)
Important	5	(1/5)	(4, 5, 6)	(1/6, 1/5, 1/4)
Intermediate value	6	(1/6)	(5, 6, 7)	(1/7, 1/6, 1/5)
Very important	7	(1/7)	(6, 7, 8)	(1/8, 1/7, 1/6)
Intermediate value	8	(1/8)	(7, 8, 9)	(1/9, 1/8, 1/7)
Extremely important	9	(1/9)	(9, 9, 9)	(1/9, 1/9, 1/9)

Step 2: Consistency check: The consistency ratio of each expert need to be determined to ensure the reliability of the survey outcomes [76], [77]. The consistency ratio (CR) values given by the experts are regarded as acceptable if it is calculated as lower than 0.10 (or 10%). Otherwise, the experts are regarded as inconsistent, and revised pairwise comparisons are requested from the corresponding expert [76], [78]. Calculation procedures to check the consistency can be found at [42].

Step 3: Attaining group decisions: The linguistic variables that were taken from each expert individually were converted into the corresponding triangular fuzzy scales for each pairwise comparison matrix. Then, group decision is augmented by taking the geometric mean values of the fuzzy scales [77], [79]:

$$l_{ij} = \left(\prod_{k=1}^{K} l_{ijk}\right)^{1/K},\ m_{ij} = \left(\prod_{k=1}^{K} m_{ijk}\right)^{1/K},\ u_{ij} = \left(\prod_{k=1}^{K} u_{ijk}\right)^{1/K} \quad (1)$$

where K is the total number of respondents.

Step 4: Application of Chang's extent analysis: Chang's [74] extent analysis was utilized to identify weights of barriers to smart contract adoption. The steps of Chang's fuzzy extent analysis can be found at [74].

4. RESULTS

In the fuzzy AHP implementation, consistency ratios of each expert were checked. In case of an inconsistency, the corresponding evaluations were revised, and the data collection step was finalized after all the matrices were found consistent. In addition, assessment of experts' consistency proves that the AHP method can be an effective tool in selection and/or prioritization problems, addressed in the literature [59]. The results of consistency analysis are shown in Table 4. Findings show that all experts were consistent with their judgments in each cluster (barrier category, financial, technical, security/technological, and time). Therefore, further analysis of fuzzy AHP was applied.

Table 4 - Consistency ratios of experts.

Expert ID	Category (%)	Financial (%)	Technical (%)	Security/ Technological (%)	Time (%)
Expert 1	4.31	0.71	8.89	2.34	9.42
Expert 2	4.31	7.45	9.62	1.64	7.64
Expert 3	6.95	4.19	8.73	9.14	8.27
Expert 4	2.64	2.43	9.45	7.63	9.42
Expert 5	8.37	6.33	7.42	8.13	9.16
Expert 6	5.33	2.65	9.89	9.50	8.19
Expert 7	4.50	8.15	8.29	7.87	6.42
Expert 8	0.00	0.00	8.60	7.86	8.93
Expert 9	5.16	1.90	4.64	3.01	6.39

Fuzzy AHP analysis results of barrier categories are presented in Table 5. It was found that the financial and technical aspects were the most significant operational barrier groups with a weight of 0.4165 and 0.2379, respectively. Time (weight: 0.1634) and security / technological (weight: 0.1822) barrier categories were determined less significant.

Table 5 - Weights and ranks of barrier categories.

Barrier category	ID	Weight	Rank
Financial	Fn	0.4165	1
Technical	Tc	0.2379	2
Security/Technological	St	0.1822	3
Time	Tm	0.1634	4

The findings related to individual barriers under each barrier category are shown in Table 6. Among the evaluated barriers, the experts highlighted the significance of Tc3 (*Irrevocable nature of smart contracts*) and Tc6 (*Incorrect coding and interoperability issues*) compared to other barriers in technical category. Tc3 and Tc6 were assessed with weight values of 0.2201 and 0.1964, and Tc1 (*Lack of experienced personnel*) was found the least significant barrier. Among the financial barriers, Fn1 (*Expensive and clunky drafting and registration process*) was the most significant financial barrier with a weight of 0.3915, and the rest of the barriers in this category were all determined with weights of less than 0.25.

In terms of security/technology category, the respondents emphasized their concerns related to the security of the confidential data used in smart contracts. In line, the findings illustrated that St2 (*Privacy issues in terms of information security*) and St3 (*Possible cyber-attacks/security risks*) were the most critical barriers (0.2488 and 0.2483), while experts considered St5 (*Error prone nature of transactions in smart contracts*) as the least challenging barrier. Regarding time category, respondents highlighted the features particular to construction projects and addressed that Tm1 (*Requirement of excessive time for approval procedures in construction*) and Tm2 (*Difficulty in setting deadlines and original time scales*) were the most critical barriers limiting the use of smart contracts with importance scores of 0.2635 and 0.2196, respectively. On the other hand, Tm5 (*Long lasting negotiation process in construction*) and Tm4 (*Time consuming process of developing the contract draft*) were the least significant time-related barriers.

The ranking of the barriers might be sensitive to the degree of fuzziness in the opinions of experts. Therefore, sensitivity analysis was employed to ensure the stability of the proposed approach under different degrees of fuzziness [71], [80]. Accordingly, the degree of fuzziness ranged between 1 and 2 with a step of 0.2 to explore whether the ranking of barrier categories and barriers change. Figure 2 and Figure 3 show the results of sensitivity analysis regarding barrier category and barriers in each category, respectively. The results show that the developed decision framework and rankings attained were stable under diverging degree of fuzziness.

Table 7 and Table 8 show the ranking difference based on the roles, organization types, and sectors of the experts, in terms of main categories and barriers, respectively. Findings show that all the participant types assessed “financial” category at the top. While experts involved in the managerial team considered “security/technological” as the second most significant category, other groups regarded as the third or fourth category in the rank (Table 7). Regarding barriers, it is especially worth mentioning that Fn4 (*Human resource cost*) is of paramount significance for the majority of expert groups, apart from public and client groups.

Interestingly, even though Tc2 (*Complexity in draft development*) was among the top five barriers when judgments of the experts from client are considered, other groups had opposite views (Table 8).

Table 6 - Weights and ranks of barriers.

Barrier category	Barrier ID	Weight	Rank	Overall weight	Overall rank
Technical	Tc1	0.1192	6	0.0284	18
	Tc2	0.1441	4	0.0343	13
	Tc3	0.2201	1	0.0524	5
	Tc4	0.1344	5	0.0320	14
	Tc5	0.1857	3	0.0442	9
	Tc6	0.1964	2	0.0467	6
Financial	Fn1	0.3915	1	0.1631	1
	Fn2	0.2112	2	0.0880	2
	Fn3	0.2016	3	0.0840	3
	Fn4	0.1957	4	0.0815	4
Security/ Technological	St1	0.2098	3	0.0382	11
	St2	0.2488	1	0.0453	7
	St3	0.2483	2	0.0452	8
	St4	0.1637	4	0.0298	17
	St5	0.1294	5	0.0236	19
Time	Tm1	0.2635	1	0.0431	10
	Tm2	0.2196	2	0.0359	12
	Tm3	0.1947	3	0.0318	15
	Tm4	0.1918	4	0.0313	16
	Tm5	0.1304	5	0.0213	20

Table 7 - Ranks of barrier categories based on expert profile.

Categories	Overall	Public	Private	Managerial	Engineer/architect	Client	Contractor	Consultant
Financial	1	1	1	1	1	1	1	1
Technical	2	2	2	4	2	2	2	4
Security/Technological	3	3	4	2	4	3	3	3
Time	4	4	3	3	3	4	4	2

Table 8 - Ranks of barriers based on expert profile.

Barriers	Overall	Public	Private	Managerial	Engineer/architect	Client	Contractor	Consultant
Tc1	18	14	17	19	10	8	18	17
Tc2	13	7	15	17	8	4	14	16
Tc3	5	5	5	15	2	3	8	12
Tc4	14	15	16	18	9	10	15	15
Tc5	9	16	7	13	7	11	6	14
Tc6	6	10	6	14	6	5	12	13
Fn1	1	1	1	1	1	1	1	2
Fn2	2	2	4	2	5	2	5	3
Fn3	3	8	2	3	3	6	2	8
Fn4	4	11	3	4	4	15	7	1
St1	11	4	14	9	16	7	19	11
St2	7	6	9	5	16	13	3	5
St3	8	3	10	6	16	9	4	10
St4	17	13	18	10	16	12	11	17
St5	19	17	20	16	16	14	20	17
Tm1	10	12	8	7	11	16	9	4
Tm2	12	9	11	8	14	18	10	6
Tm3	15	18	12	11	13	19	13	7
Tm4	16	19	13	12	12	17	16	9
Tm5	20	20	19	20	15	20	17	17

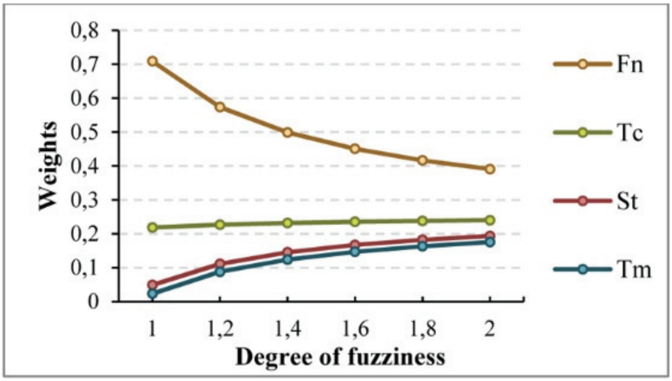

Figure 2 - Sensitivity analysis of main barrier categories.

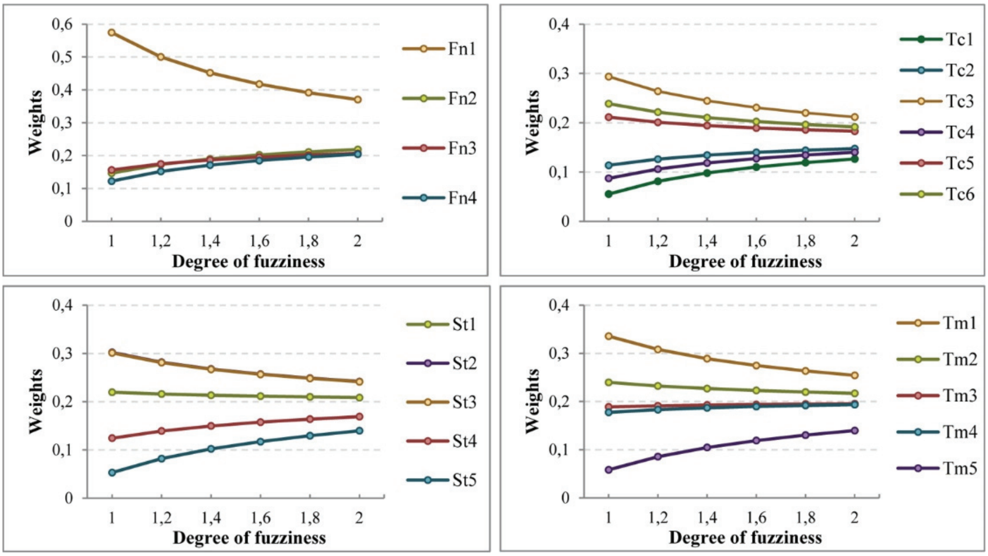

Figure 3 - Sensitivity analysis of categories a. Financial, b. Technical, c. Security/technological, d. Time.

5. DISCUSSION

Digital transformation in many industries including the construction industry is developing with the contribution of blockchain technology and smart contracts [37], yet the projects still suffer from budget constraints. Most of the companies act slowly in adopting recent technologies due to limited investment budgets. According to Yang et al. [81] cost is a key concern in adopting blockchain systems. Costs associated with smart contracts include initial drafting and registration cost (Fn1), upskilling cost (Fn2), updating cost (Fn3), and human resource cost (Fn4). In line with the results of this study, Mason and Escott [35] also highlighted the concerns of stakeholders about several types of costs associated with smart contracts such as time and cost required to educate human resource, system installation, and having qualified employees. Omar and Nehdi [82] emphasized that when applying any information technology in the construction sector, the update costs of the hardware, the needs for technical support personnel in the organizations, and the training of the employees become critical concerns. Similarly, Li et al. [14] underlined that the shortage of suitably upskilled, sufficiently trained, and talented personnel can be significant barriers for a construction company during digital capacity improvement processes. Recruitment and training the qualified employees can be costly [83], however, they are the prerequisites of successful transitions. Sonmez et al. [84] revealed that technical staff in construction projects do not feel confident about using newly developed systems if they are not familiar with implementing and supporting these advances. Therefore, gaining control over the information management system and contract management with qualified employees, the contribution of smart contracts may become more significant for the organizations.

Smart contracts can be characterized by immutability and inflexibility, yet changes and updates are common in construction contracts. Therefore, additional manual efforts and computational overheads related to use of smart contracts can also incur significant costs during the transition period from conventional to smart contracts. Security testing can help the prevention of vulnerabilities in terms of information security that may require a huge number of updates [85]. Hence, updates are technically applicable when the contract has repairable vulnerabilities [86]. Another important barrier is the privacy issues of smart contracts (St2) in the projects, which reflects the findings of Wang et al. [86] addressing privacy issues related to "contract data" and "personal data". In line with the results regarding financial category, Li et al. [87] and Agapiou [88] also addressed the possible financial losses in sustaining smart contracts due to security vulnerabilities. Automated vulnerability detection can be a solution to overcome this concern [85]. Contractual clauses, specific and/or general conditions, and risk mitigation instruments are critical in contract management. In this context, robust solution mechanisms and clear procedures are required to ensure the security of smart contracts throughout their life cycle [89].

Another type of problem was related to the "*irrevocable nature of smart contracts* (Tc3)". This result emerged from the analysis corroborates the earlier findings of some scholars [39], [90], who considered Tc3 as one of the risks in the implementation of smart contracts. Once smart contracts are initiated, the outcomes cannot be stopped as the procedures are coded by rule-based operators [48], [91]. This feature may be catastrophic if contract codes are incorrect [22]. To overcome this barrier, critical information should be shared, read, and approved by all members using the blockchain network with respect to the consensus between client and contractor, while not being changed or removed by any members [8], [22].

The results showed that the "*requirement of excessive time for approval procedures in construction* (Tm1)" was the most critical time-related concerns of construction professionals. In line with this finding, late approvals are acknowledged to be the major source of project delays in construction projects [92]. This outcome contradicts with one of the major objectives of smart contracts, which is to facilitate and accelerate the approval procedures during the initial drafting and information management processes throughout project execution [93]. However, as Perera et al. [49] addressed, the construction industry involves many approval processes since it includes numerous organizations in supply networks. Therefore, diligent organization of approval management systems is essential during the smart contract drafting stage. As stated by Das et al. [89], smart contracts can be adopted to ensure both the information approval workflow and document management systems.

As provided in Table 7 and Table 8, the experts from different roles and organization types have stated some similar as well as some opposite views about barriers. For instance, "financial" category was quite important for all expert types regardless of stakeholder profile. The experts from managerial team considered the "security/technological" category as more significant than others (Table 7). The most reasonable reason behind this logic is that handling unwanted transactions and security are huge challenges for management-level personnel [94]. Besides, the "*privacy issues in terms of information security* (St2)" was among the top three barriers in terms of the assessment of the experts from contractor firms

(Table 8). This can be supported with the results of Ahmadisheykhsarmast and Sonmez [43], who highlighted significant concerns of contractors about privacy issues.

On the other hand, other than operational barriers, several studies have critically addressed administrative [42] and legal issues [88] in the adoption of smart contracts in the construction industry. Although operational barriers were focused in this study, legal barriers and awareness/consciousness of project stakeholders towards smart contracts should be considered to manifest the successful implementations. For example, Agapiou [88] highlighted that enforceability, data protection and privacy, intellectual property rights, and dispute resolution were crucial barriers to designing smart contracts in the context of legal and regulation policies. These issues are of greater concern in raising legal uncertainty as a result of rapid changes in technology. Hence, new technological solutions requires updating existing legislation and developing new policies for better contract administration [95].

There are different legislative systems, and smart contract development can change accordingly. Law developments in Anglo-Saxon legislative system (also known as common law, followed in UK, USA, Canada, Australia, etc.) is largely based on past court decisions, which serve as an authority for future decisions. On the other hand, Continental European system (the most commonly followed legal system, e.g., Germany, France, Italy, and Turkey) relies on extensive codes that highlight the rules and procedures. In Anglo-Saxon system, a contract is regarded as a “promise” for a “counter-provision”, while it is considered as an “agreement” in the Continental European system [95]. Kasatkina [95] stated that the identification of the contractual inception of a smart contract varies between approaches in the continental legal system family and Anglo-Saxon law. The researcher addressed that legislative experience of smart contracts is different in the EU and the USA, for example, and there is no legislation for the implementation of smart contracts in most countries. Thus, technological barriers can be minimized, and costs can be achieved with the help of standardization and common procedures at legislative level.

Furthermore, it is also worth mentioning that the use of smart contract is related to the awareness of senior management in construction firms [96]. Ameyaw et al. [41] stated that awareness of stakeholders is critical to aiding its adoption process. This is further confirmed by Elbashbishy et al. [97], in which the researchers emphasized that increasing the awareness and capabilities of staff is one of the important factors to the widespread adoption of blockchain technology, which integrates smart contracts in construction contracts.

6. IMPLICATIONS FOR PRACTITIONERS

This study proposes a smart contract implementation framework based on life cycle of contract management (drafting, review/approval, implementation, and closure/renewals processes) (Figure 4). To develop a practical structure, responsibilities of all contracting parties need to be clarified and included. With the integration of contractual claims, potential disputes among the parties related to contract clauses, progresses, and payment issues can be mitigated or prevented. Unforeseen conditions, discrete requirements of the projects, and change orders should also be included in the smart contract drafting process to perform effective contract administration [42]. Rendering contract documents in their digital forms and automated legal review of contract clauses can also help minimize uncertainties and incompleteness, while enabling a better control of contract requirements. Blockchain network can be used in the review and approval process of smart contracts to monitor workflows, automate approvals, and perform updating without human interference [93]. During the implementation process, automated control and monitoring systems, artificial intelligence, optimization algorithms [8], and dynamic operations (security analysis, automatic updates and self-destruction etc.) [86] can be useful for effective administration. Once a setback is observed or predicted, IT team members can be informed earlier to minimize failure in contract administration along with the regular maintenance [8]. In the closure phase, all data should be collected via project database and contract can be closured by reporting errors/failures to help improve smart contract drafts in future projects.

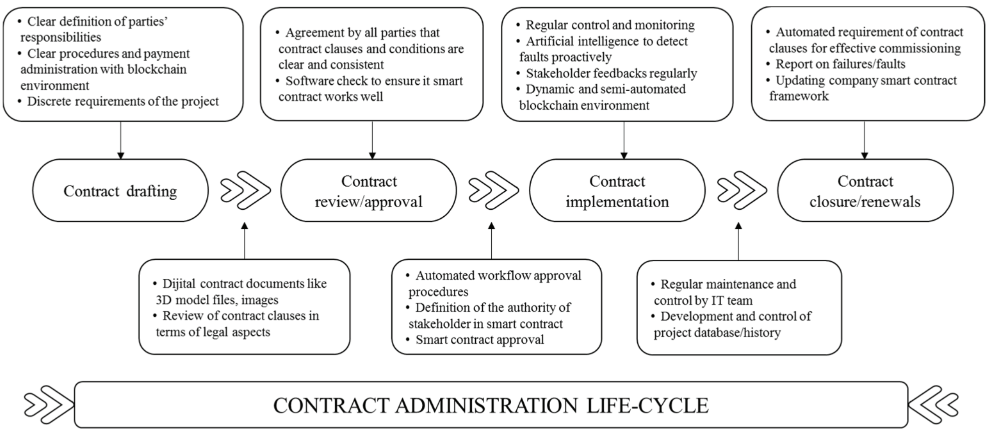

Figure 4 - Proposed smart-contract adoption framework.

Construction managers are the major authorities in construction projects that are responsible to facilitate effective communication management methods and establish sustainable working environments through useful means for engineers/designers/site supervisors. They need to look for applicable decision strategies and integrate appropriate technological solutions into their organizations to add value. With the continuously evolving technology, construction managers realized how crucial technological knowledge and capabilities are for organizational development [98]. Hence, they need to work with advanced technological tools to enhance project management techniques and their competitive advantage in the construction sector. Contract administration based on "smart contract" technology has great potential to improve the efficiency of construction projects. The adoption of smart contracts with digital documents and automated approval systems enables implementation of different control strategies for more robust contract administration processes and fosters stronger relationships among project parties. However, it is essential for the construction managers to handle the critical barriers such as "expensive and clunky drafting and registration process", and "cost of upskilling" in the process of using smart contracts. Therefore, the framework promoting robust contract management can be useful for improved project performance.

7. CONCLUSION

Digital management of contracts is expected to have significant impacts on the occurrence of conflicts, claims, and eventually disputes in construction projects. Smart contracts, which have the potential to change contract implementation process in construction projects, are one of the most frequently exploited technological improvements in recent years. However, construction managers may hesitate adopting smart contracts due to many operational barriers in the life cycle of the projects. To minimize the concerns of project teams and stakeholders, this study aims to explore the operational barriers against the adoption of smart contracts and to develop a model in the adoption process for construction projects.

In the present research, the operational barriers were defined under four categories: technical, financial, security/technological, and time, by conducting FGD with construction professionals. This step was followed by the fuzzy AHP analysis to identify the weights of the barrier categories and twenty individual barriers that were listed under these categories. Based on results of the fuzzy AHP analysis, expensive and sluggish drafting and registration process, cost of upskilling, cost of updates required frequently, cost of adequate human resource, and irrevocable nature of smart contracts were found to be the most significant barriers. The stability and robustness of the proposed approach and the research findings under different degrees of fuzziness were checked through sensitivity analysis. Furthermore, this study presents a smart contract implementation model for the construction projects that is expected to contribute to both directly and indirectly the performance and effectiveness in construction companies. Moreover, engineers and/or managers who have a significant role in construction management could facilitate evolution of contract administration practices into the digital platform by adopting this model.

Even though this study presents an insight into the barriers that may be faced in the implementation of smart contracts, it still poses some limitations. For instance, this study adopted several research techniques that rely on subjective evaluations of the experts in both fuzzy AHP and FGD method applications. Therefore, validation of the results with real-life observations can be a useful research direction to observe which operational barriers result in which hardships and to what extent. Additionally, the opinions of a limited number of experts from the Turkish construction industry were incorporated into this study. Hence, the number of experts can be increased in future studies by including the judgments of experts from different countries and industries. On the other hand, this study examined only the operational barriers to smart contract adoption. However, legal barriers, another important concern of stakeholders for implementing smart contracts, were not considered within the scope of this study. Therefore, significant barriers to smart contracts based on Turkey's legal structure can be investigated as a future research direction. Overall, the smart contract adoption framework proposed in this study is expected to help practitioners reduce the concerns of project stakeholders that hinder the adoption of smart contracts. The findings of this study can be used by both construction managers and technical engineers to upgrade the conventional contract forms and exchange them with more robust and automated contract forms.

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