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Development of Knowledge Management Risk Framework for the Construction Industry

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Abstract: The construction industry (CI) has complex, human-based, dynamic, and fragmented structure. Therefore, effective Knowledge Management (KM) is the key to eliminate risks and ensure project success. However, KM applications in CI are behind other industries. Moreover, construction companies try to integrate Information and Communication Technologies and Information Systems. However, their success and adaptation levels are below expectations due to their unawareness of KM risks. Furthermore, there is a lack of knowledge identification, conceptualization, and development of a comprehensive KM risk framework. Therefore, this study aims to identify KM risks and to develop a KM risk framework. The research followed a literature review, Focus Group Discussion (FGD), Fuzzy TOPSIS, and an expert review meeting. Using the Fuzzy TOPSIS methodology, the sequence of KM risks and their weights were uncovered. According to the analysis results, operational KM risks were found more important than technological and human-related factors. In addition, "Financial risks" were revealed to be the most outstanding risk in KM. As a final step, the expert review meeting was held. The reviews revealed that KM risks are of note and yet ignored. Another inference from expert reviews showed that the developed framework was beneficial to manage KM risks in CI.

Keywords: Knowledge Management; risk management; construction industry

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1. Introduction

The construction industry is one of the propelling industries behind the economic growth of countries. However, the productivity rate of the construction industry is lower than other industries. From the practitioners' and academics' perspective, Knowledge Management (KM) activities and processes are known as a facilitator of the productivity rate of the construction industry. Architecture, Engineering and Construction (AEC), and Engineering, Procurement and Construction (EPC) industry companies are highly knowledgeable and experience-based companies. Thus, the capabilities of AEC/EPC companies, such as market knowledge, technological knowledge, and project management knowledge, considerably affect their market performance [1]. In addition to market performance, KM affects time-cost overruns, reworks, changes and mistakes on construction sites [2]. Yap et al. [3] also stated that there is a direct relationship between lack of KM and failures in construction projects. In other words, managing project knowledge helps to increase project success [4]. Therefore, KM-related processes, activities and technologies have gained importance in managing intensive data [5].

Besides these, construction projects have started to demand more skills, mindsets, innovative models and approaches [6]. Consequently, the construction industry is highly competitive. One fact this study has brought to light is that developing sustainable and responsive strategies through KM practices is vital to handle competition, demands, and changes in the environment [7,8], since KM helps to manage critical knowledge and generate new knowledge to enable achieving organization objectives [9]. Within this context, Vaz-Serra and Edwards [10] also stated that organizations can lead to change and facilitate innovations with KM and knowledge acquisition to achieve organizational objectives.

However, according to Deng et al. [8] and Joaquim et al. [11], the implementation of KM in the AEC industry is problematic due to the uniqueness of construction projects, high time pressure, focusing on short-term deliveries, fears of managers from disclosure of mistakes, instability of labor forces, project-based structure of construction industry, complexity of projects, and unstructured data resources. Moreover, limited time and resource restrictions are significant barriers to transferring knowledge from projects to the knowledge base [4]. Therefore, Yap et al. [3] stated that implementing KM is not at the intended level in the global construction industry. In other words, KM applications in the construction industry have not achieved the targets defined before successfully [3]. Construction activities are based on highly labor-intensive activities. If KM is not implemented in the organizations properly, the tacit knowledge, which depends on the skills, ideas, and worker experience, comes into prominence [3].

In the AEC industry, KM is implemented with the use of traditional methods. If KM systems are adapted to enable KM in the organization and there is no exact specification for KM processes, KM becomes more difficult and riskier [11]. Companies try to adapt KM systems to be competitive. However, the adaptation of KM systems may be beyond the organization's capacity. Sometimes, this may end up in failure or disaster [10]. Therefore, KM-related risk management comes into prominence.

The studies showed that the lack of risk management in international projects costs heavy losses to global contractors [12]. KM-related risks are one of the areas that require high attention. Even though previous projects allow for the identification of project risks, risks related to KM generally stay hidden as tacit knowledge due to high staff turnover [12]. However, KM risks are not limited to loss of knowledge due to tacit knowledge, since lots of data is produced with new technologies [13]. Within this context, the most disruptive technological invention was the introduction of computers [9]. Computers have played an essential role in capturing, storing, and distributing knowledge. Therefore, computers and other technologies are open to new risks, such as data leaks and hacker attacks [13]. Risk management is vital to reveal hidden barriers or hazards that can lead to undesired results in construction projects and eliminate the risks mentioned above [14]. Studies showed that KM-related risks are ignored in the literature [14,15]. While the aim of risk management is to increase the effect of good occurrences and mitigate or eliminate negative occurrences to facilitate achieving projects' targets [14], knowledge risk was defined as "a measure of the probability of adverse effects of any activities engaging or related somehow to knowledge that can affect the functioning of an organization on any level" by Durst and Zieba [13]. Bahamid et al. [14], further stating that the incapability to manage project risks induces overruns in project costs, delays, productivity issues, underperformance, and conflicts. Within this context, the mismanagement of knowledge and risks has the same effects on the projects owing to experts' subjective opinions based on project uncertainties.

In the literature, Durst and Zieba [13] focused on identifying knowledge risk rather than industry-specific solutions. Specific to the construction industry, knowledge risks have not been identified yet. Moreover, the literature focuses on the contribution of KM to risk management and other projects or industry success factors [11]. However, risks existing in KM practices are ignored. Aside from the common use of Information and Communication Technologies (ICTs) and Information Systems (ISs), KM is a practice of special interest [3]. Therefore, this study aims to determine KM-related risks and develop a KM risk framework.

2. Research Background for Knowledge Management (KM) in the Construction Industry

Knowledge needs to be updated and shared among stakeholders during the building life cycle to make a well-thought-out decision [11]. Egwunatum and Oboreh [7] stated that KM necessitates the interaction of four components: people, process, IT, and strategy. According to the authors, only the right people can create trustable knowledge. However, human resources are not enough by itself. Knowledge needs to be stored in the ICT or IT tools. Besides these, the implementation of the right strategy not only supports KM pro-

cesses but also productivity, performance, and progress in the organization. Kanapeckiene et al. [16] defined KM activities for construction projects. According to the KM activities, construction companies should ensure the mechanism in which project information and knowledge gathering, knowledge acquisition, best practice knowledge data base creation and knowledge-based decision support is implemented in other projects. In the project information and knowledge gathering, the companies should enable the gathering of all information from all stakeholders. The second part of the mechanism was explained as knowledge acquisition, consisting of explicit and tacit knowledge. The companies should prepare and regulate how the knowledge is formulated and documented. However, these processes should be supported with the use of ICT and IT technologies such as databases. After that, data should be categorized according to their importance. Thus, important and valuable knowledge can be separated. In the final step, knowledge should be used and their results should be reported. In the literature, many AEC industry-related KM studies have been conducted to make the KM process healthier. Upcoming subsections summarize the studies.

2.1. Review Articles and KM Importance

Moshood et al. [4], Yepes and Lopez [17], Yap et al. 30, and Benavides and Piqueras [18] compiled the current body of knowledge and made a bibliometric analysis. The authors investigated knowledge transfer, KM studies in the construction industry, updated KM components and their effects on the construction industry, and developments in KM and new aspects of KM. The study findings of Yepes and Lopez [17] emphasized that knowledge creation activities are still low in the construction industry since knowledge exploitation's impact on organizations is still unclear. Yap et al. 30 revealed that KM is affected by knowledge sharing, collaboration, learning from mistakes, training, and KM-related strategies. Besides this, the authors stated that knowledge is created with the processing of project failures, life learning activities of individuals, and brainstorming activities. Benavides and Piqueras [18] emphasized that there are no coordinated KM strategies. Therefore, the companies must spend much effort to be competitive.

Moreover, the use of KM and its importance have been mostly investigated by different countries from different perspectives. While Fong and Kwok [19] aimed to find out the utilization success of KM systems in the Hong Kong construction industry by separating it at the organizational and project level, Tan [20] investigated how KM should be implemented due to failures in knowledge generation and dissemination in Singapore construction industry. Additionally, whilst Forcada et al. [21] aimed to reveal perceptions related to KM implementations specific to design and construction companies in Spain, Kivrak et al. [22] investigated how explicit and tacit knowledge is managed in Turkish construction companies in terms of knowledge generation, storage, and dissemination. According to Tan's [20] study findings, KM needs to be performed at the industry level. To enable this, governments need to promote investing in human capital and the IT infrastructure, coordinating efforts via research and funding, and creating local knowledge. Fong and Kwok [19] found that the use of KM is substantial and beneficial for both organizational and project levels. Moreover, the study findings showed that codification and personalization (KM strategies) should be implemented equally at project and organization levels. Study findings of Kivrak et al. [22] showed that most construction companies have no KM strategy and do not have a systematic approach to managing tacit knowledge specific to the Turkish construction industry. Therefore, the authors proposed a web-based knowledge platform to manage knowledge effectively. Forcada et al. [21] found out that the awareness of Spain construction companies about KM benefits is high. However, they have no systematic KM implementations. In other words, Spain and Turkey show similarities in terms of KM implementations. The perception differences between design and construction companies were also discovered.

Besides these studies, Yap et al. [23] focused on explaining the importance of knowledge and experience in delivering projects successfully. Moreover, while Abuezhayeh

et al. [24] investigated the effect of KM and business process management on the decision-making process, Ribeiro [25] aimed to find out how knowledge is managed in project-based companies with the use of case study methodology. The findings showed that arranging seminars, workshops, and rewards motivates workers to implement KM systems [24]. At the same time, the findings answer the questions of how effective KM activities are implemented, which knowledge needs to be managed in the organization, how the knowledge generation process needs to be, and what are the enablers and barriers of knowledge dissemination activities [25].

2.2. KM Implementation Benefits and Barriers

The KM implementation benefits and barriers are among the most investigated research topics. Yap et al. [3] investigated the relationship between KM tools and techniques. The article targeted informing construction companies more about the benefits of KM and introducing KM tools and techniques. The analysis results indicated that KM helps to increase competitiveness, innovativeness, customer satisfaction, profits, and productivity. Marinho et al. [11] tried to explain KM benefits, KM barriers, and how knowledge can be generated. The study findings emphasized that knowledge sharing and tacit knowledge transfer between workers are the most effective ways to enable KM. Moreover, the authors found that KM technologies are not enough alone. They need to be supported by organizational factors. Moshood et al. [26] aimed to discover and acquire more on knowledge transfer, knowledge sharing, and barriers related to knowledge transfer. After the study, the authors determined the factors for a successful knowledge transfer between professionals. Egwunatum et al. [7], Yap and Lock [2], and Aghimien et al. [27] aimed to find out the level of awareness of small and medium-sized companies about KM, barriers, benefits, and techniques. Ferrada and Serpell [28] investigated the development level of KM, KM activities, KM tools, and KM barriers for Chile's construction industry. Similarly, Esmi and Ennals [29] investigated KM advancements and barriers in construction companies in the United Kingdom (UK). The study findings showed that the companies in the UK are heavily dependent on tacit knowledge and are insufficient to implement KM due to the lack of academic qualifications and low Information Technology (IT) use. Additionally, Guto and Wasiu [30] found barriers to KM implementations in Nigeria. These study findings emphasized that lack of review, lack of learning process, poor communication network, technology, insufficient training, lack of capital, lack of IT support facilities, transforming information to knowledge, lack of coordination, reluctance of workers for knowledge sharing, risk perception related to sharing knowledge, limited time, participation of experienced professionals, organization culture, managerial support, motivation and time for adaptation of KM systems are the most significant barriers for the KM. The authors proposed to hire talented and experienced workers to adopt KM systems. Guribie et al. [31] focused on identifying human-related KM barriers since the authors asserted that knowledge is hidden in social groups. Therefore, barriers were categorized under four categories: individual level, team level, organizational structural level, and project level. Akhavan et al. [32] aimed to find out KM barriers and to categorize these barriers specific to Iranian construction companies rather than only human factors. However, Akhava et al. [32] identified categories as individual, organizational, technological, contextual, and cross-project barriers. The authors proposed a three-phase approach to overcome these barriers: KM at intracompany, improvement of KM implementations, and generic factors. Shokri-Ghasabeh and Chileshe [33] investigated the barriers to integrating learnings from past projects into company knowledge management systems. The study revealed that only limited data related to project proposals was saved by Australian contractor companies, even though it is ruled by the government.

2.3. KM Impact on Performance Management

The impact of KM on construction project performance or construction company performance is one of the trend topics. These studies are aimed to find out the impact

of KM on non-financial performance of construction organizations for Thailand [34]; KM factors affecting construction companies' performance [35]; KM factors (knowledge leadership, knowledge culture, knowledge processes, and knowledge technology) affecting construction projects' performance specific to United Arab Emirates [35]; the impact of KM success factors on project management performance [36]; the impact of knowledge creation on construction project performance during COVID-19 [37]; the effects of project risk management, project planning and knowledge management on project success [38]; the relationship between KM process and company performance [39]; the effectiveness of KM systems in terms of knowledge infrastructure capability, knowledge process capability and their impact on construction company performance [40]; and the relationship between KM and growth performance of construction companies in Malaysia [41]. Findings showed that human resources management has a mediating impact on KM and organizational performance. In other words, organizations solemnize activities and policies that facilitate knowledge-sharing activities among workers [34]. Alhammadi et al. [35] found 31 factors that classified under knowledge leadership (the most important factor group), knowledge culture, knowledge process, and information technology. Against Alhammadi et al. [35]'s study, Mohammed et al. [35] found that knowledge technology is the most important factor affecting project performance. Gunasekera and Chong [36] considered 9 KM success factors; culture, leadership, organizational structure, KM technologies support, capabilities, training, teamwork, performance measurement, and benchmarking. According to analysis results, benchmarking, leadership, teamwork and capabilities were the most substantial factors during the KM implementation. Yusof et al. [41] confirmed that KM positively affects company growth. ElFar et al. [40]'s study results showed that knowledge infrastructure capability and knowledge process capability affect business performance. Wibowo and Zhabrinna [39] showed that there is a relationship between KM and company performance. However, Alchammari et al. [38]'s findings indicated that project planning and risk management play a crucial role in project success. However, the same effect could not be observed for KM.

Boamah et al. [42] investigated the facilitating factors of KM implementation in the construction industry. According to the study findings, tacit knowledge, motivation, knowledge-based decision-making, and strategic planning were the most decisive factors in achieving strategic targets. Also, the authors proposed 17 actions to enable effective KM. Othman et al. [43] evaluated KM implementations in consulting construction companies in Malaysia. As a result of the evaluation, key performance indicators for KM specific to Malaysia were identified. The study findings confirmed that KM improves the decision-making process and promotes innovations. Dang et al. [1] investigated the effect of KM on the market development of construction companies. Analysis results showed that KM influences the market development. Moreover, this effect is bigger on small and medium-sized companies than large-sized companies. Even though the study findings showed the importance of KM for small and medium-sized companies, these companies are reluctant to invest in the KM system because of limited monetary resources and unclear benefits.

2.4. KM Related Technologic Developments

Denga et al. [8] compiled research articles and reports to reveal the historical development process of KM information technologies and show recent technologies. The study analysis results emphasized the importance of training to increase awareness about KM, participation in standardization efforts to enable interoperability, and government participation in the evaluation process of KM information technologies. Vaz Serra et al. [10] developed KM systems that help to capture knowledge and enable knowledge utilization without changing too many organizational processes. Kanapeckiene et al. [16] focused on losing the tacit knowledge of project managers when the construction projects conclude. The authors proposed a KM system to impede the loss of tacit knowledge. One benefit of the KM system is that it enables one to make the most rational decision automatically. While doing this, the decision is chosen from many alternatives generated by the KM system.

Yang et al. [44] proposed a system to calculate the benefits of KM system use. The study compiled KM systems, the benefits of KM system use, and performance assessment of KM systems. The study findings showed that engineering consulting firms could enable a 48.7% time reduction in data collection and save 25.3% staff hours in preparing service proposals.

2.5. KM Models

Studies indicate that implementing and adopting KM in organizations or projects is problematic in the construction industry. Therefore, authors have proposed many KM models. The main target of the proposed models is to explain the KM model to benefit from KM effectively in organizations [45]; to explain the relationship between KM maturity and company performance, Hartono et al. [46]; to identify factors affecting KM implementations in the Libya construction industry, Khalifa and Jamaluddin [47]; to combine KM and business process reengineering to promote company innovativeness and competitiveness [48]; to evaluate of KM implementations of construction companies, Kale and Karaman [49]; to create K-mapping models enabling integration of project related components and technologies, Yun et al. [50]; and to enable more efficient and effective structure for the construction industry [51]. According to these study findings, Hartono et al. [46] stated that the relationship was only significant for large-size companies and projects with high complexity. Khalifa and Jamaluddin [47] found that a relationship between organizational culture and the use of KM tools does not exist. The model proposed by Kale and Karaman [49] includes evaluation of KM implementations, identification of disadvantages, competitive advantages and disadvantages, and revealing managerial actions to improve KM applications. The model proposed by Adi et al. [45] consists of the improvements in KM implementation processes, making the decision process easier, obtaining competitive advantages, enabling innovations, and increasing KM performance. Yun et al. [50] proposed four K-mapping models (narrow-based, construction personnel-based, construction-process-based, and broad-based) that are used to illustrate key processes, methods, and tools with the sources, flows, constraints, and terminations of tacit and explicit knowledge. According to the study results, K-maps need to be developed with a strategic perspective and should meet the organizational needs. The proposed models can be used according to their personnel capabilities and work process.

The research revealed that no study has aimed to identify risks related to KM specific to the construction industry. Durst and Zieba [13] identified risks related to KM for all industries rather than the construction industry. Within this context, this study has been carried out by assuming that new risks will arise since the construction sector is project-based and harder to regulate and control than other sectors. As a result of the literature review, different risks related to KM have been added to risks defined by Durst and Zieba [13].

3. Methodology

This study uses the four-step methodology in Figure 1 as a base. According to the research methodology, the factors that need to be considered in the framework were determined by a comprehensive literature review in the first step. In the second step, the framework and its components were evaluated by experts through focus group sessions. The Focus Group Discussion (FGD) session was used to discover new KM risk factors by identifying the tacit and practical knowledge of experts. As an output of the second step, reviewed and validated factors were used to create a base for the framework. In the third step, the weights of KM risk factors were determined with the fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method. The data collection in the third step was realized with an FGD session. In the last step, the introduction and validation of the KM-related risk framework were performed with expert reviews.



Figure 1. Research Methodology Flowchart.

3.1. Development of Risk Knowledge Management Framework-Literature Review

As stated in the literature review section, the identification of KM risks is unavailable, as they are specific to the construction industry. Moreover, there are limited studies related to the identification of KM risks for general purposes. Therefore, these studies and KM studies were conducted specifically to the construction industry and investigated to identify factors. The Scopus search engine was chosen to conduct a literature review due to its comprehensiveness and popularity [52,53]. As a result of the literature review, 31 factors were identified. Table 1 summarizes the literature review results.

Table 1. Knowledge management risks.

	Factors	References
	Human related factors	
H1	Knowledge hiding (Depending on individual competition)	[7,11–13,20,27,30,31,45,47,54]
H2	Knowledge hoarding (knowledge hiring depending on it is not asked of workers. Workers save the knowledge for personal knowledge)	[1,2,7,13,20,21,27,30,34,36,38,40,47,49]
H3	Unlearning depending on outdated knowledge	[6,13]
H4	Knowledge Forgetting	[13,38,40,46]
H5	Missing/inadequate competencies of organizational members	[6–8,11,17,32,42,45,50,55]
H6	Coordination risks among organization members	[7,13,17,25,36,46,51,55]

Table 1. *Cont.*

	Factors	References
	Technological factors	
T1	Cybercrime (hacking, threats of malicious software, e-mails, etc.)	[1,12,13,20,34,42,54]
T2	The use of old Technologies (the use of non-supported computer programs, etc.)	[7,13,49,50]
T3	Digitalization and innovations (i.e., development of new Technologies and deleting or manipulating the former ones)	[2,3,7,13,14,17,19,26,32,33,42,50,51]
T4	Social media (information distortion or fake news)	[1,13]
	Operational factors	
O1	Knowledge waste (non-use of potentially useful knowledge)	[12–14,29,33,34,47,51]
O2	Knowledge gaps (the difference between what the organization must know and what it actually knows)	[8,11,13,31,50]
O3	Relational risks (the disclosure of information that provides a competitive advantage to companies by involving different stakeholders in projects)	[2,8,13,22,54]
O4	Knowledge outsourcing risks (depending on activities or services made by external contractors)	[13,49]
O5	The use of obsolete/unreliable knowledge	[1,2,12,13,17,20,42,55]
O6	Misinterpretation of knowledge or improper knowledge application	[2,3,7,13,17,21,27,38,40,45,47]
O7	Espionage	[13,27,30,33,54]
O8	Enterprise sustainability risk due to resignation/dismissal of workers	[3,7,11–13,30,40]
O9	Communication risks due to noise (anything causes misinterpretation among people who communicate)	[3,7,11,13,14,17,30,31,36,38,46]
O10	Knowledge acquisition risks (acquiring partial or wrong knowledge)	[6,7,13,14,16,17,26,27,30,36,49,51]
O11	Knowledge transfer risks	[2,6,13,17,21,22,27,30–33,45,49,51,55]
O12	Merger and acquisition risks	[3,7,8,11,13,14,17,21,26,32,36,38,42,46,47]
O13	Mistaxonomy or mismanagement of Knowledge	[3,8,12–14,18,20,26,27,29,33,36,40,46]
O14	Mismanagement of KM tools and approaches	[13]
O15	Political risks	[7,12,34]
O16	Financial risks	[6,7,11,14,17,32,33,38,42,45,51]
	Operational factors	
O17	Uniqueness of projects	[6,14,31,46]
O18	Time constraints to adapt KM in the projects	[7,11,26,30,51]
O19	Organization culture	[6,14,22,27,30,51]
O20	Non-availability of guides	[30,32]
O21	Execution of projects in different geographical locations	[30]

3.2. Review of KM Risk Framework-FGD Session

Experts with diverse experience in KM reviewed the initial version of the KM risk framework. Their views offer significant opportunities to increase the usability and practicability of the proposed framework. The Focus Group Discussion (FGD) technique was chosen to learn expert opinions about the necessity of developing a KM risk framework, discovering new KM risks, and reviewing the KM risk framework and its components. Besides this, FGD reveals the meanings behind the views and gives an understanding of participants' experiences and beliefs. The FGD technique is one of the qualitative research methods. FGD is executed by a group of experts, and they can be regarded as in-depth interviews. Size, composition, and interview procedures are critical to run successful FGD

sessions. In the FGD, the participants can influence each other to create a suitable environment for discovering practical knowledge and generating innovative ideas. According to Mishra [56], FGD sessions can be used as a stand-alone method to examine subjects. Also, FGD can be performed before or after quantitative research methods to discover thoughts about the topic.

Moreover, the size and the homogeneity of participants, according to the research topic, are large, in order to obtain reliable data from FGD sessions. Within this context, the size of FGD sessions usually consists of 10 to 12 experts [56]. Therefore, the systematic expert prequalification procedure to invite them into FGD was implemented. Figure 2 illustrates the procedure. Moreover, while selecting the industrial practitioners, the author considered their familiarity with KM systems, tools and applications such as BIM, ERP, etc. Also, academicians were selected according to their studies on KM and KM-related applications. Consequently, 11 experts were invited to FGD. The expert profiles are presented in Table A1 (in Appendix A).

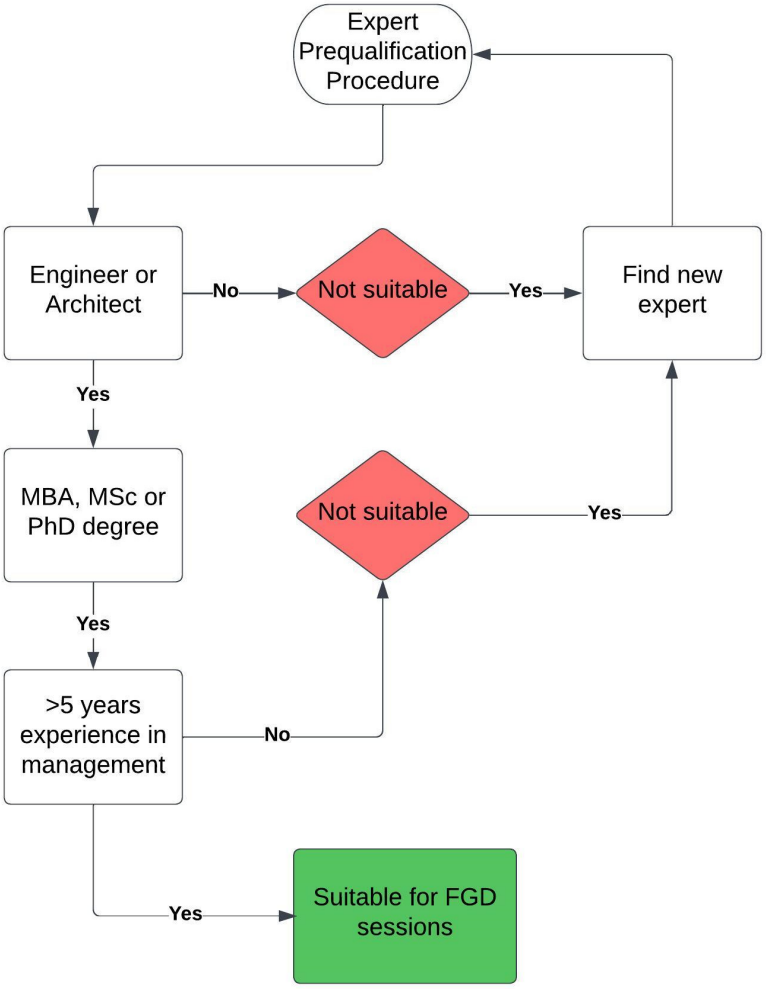


Figure 2. Expert prequalification assessment procedure for FGD sessions.

The composition of the FGD session was constructed on three stages: experts' opinions about the necessity of developing a KM risk framework, discovery of new KM risks, and review of the KM risk framework and its components. Therefore, in the first stage, an open-ended question was asked to participants to learn the necessity of the KM risk framework. According to expert responses, identification of the KM risks and its framework were a significant effort since every company tries to integrate KM into their companies to enable or improve corporate memory. However, experts asserted that companies have issues

foreseeing risks that cause failings at both project and corporate levels while adopting KM and KM tools.

In the second stage, the identified risks were shown to the experts, and their views on discovering new KM risks were asked with open-ended questions. Within this context, experts stated that the given risks are enough to evaluate KM-related risks. In other words, experts did not add new KM-related risks. In the final stage, the quantitative evaluations of experts were gathered to enable a review of the KM risk framework and its components. The 1–5 Likert scale was used to assemble their assessments. In this evaluation scale, while 1 stands for the least importance given, 5 shows the most importance given. As a result of the analysis, the minimum average value was found for "Social media" risk with a 2.45 score. Therefore, all risks were accepted as important, and all risks were used in the next step (prioritization of KM-related risks).

3.3. Numerical Analysis of KM Risk Framework to Discover Impacts of Risks

Fuzzy Techniques for Order Performance by Similarity to Ideal Solution (FTOPSIS) was employed to discover the priority ranks of KM risks. The compiled KM risks confirmed after the FGD session were assessed against occurrences, severity, and detection criteria considered in the Failure Model Effect Analysis (FMEA) approach by experts. The experts were invited into the FGD session with the use of the given logic in Figure 2. The expert profiles are given in Table A2 (Appendix A).

3.3.1. Failure Model Effect Analysis (FMEA)

Ahmadi et al. [57] stated that the most frequently used risk techniques in the construction industry are risk matrix, Monte Carlo simulation, scenario analysis methods, AHP, and Fuzzy logic assessment. The authors explained the limitations of these techniques by classifying risks into limited categories, using precise experimental and statistical data, many statistical data requirements, limited pairwise comparisons, and not as precise as probabilistic methods, respectively. Failure Model Effect Analysis (FMEA) is one of these techniques. The main target of the technique is to reveal all failures in a system, assess their effects, and plan responses for these risks. In the FMEA analysis, the risk priorities are evaluated according to their occurrences (O), severity (S), and Detection (D) [58]. In traditional FMEA analysis, every part of each risk is assessed by using 1 to 10 values. In other words, O, S, and D values are assessed with 1 to 10 values, and the evaluations are multiplied by each other. If analysis results are close to 1000, the priority of risk has more importance than other risks. However, Mohammadi and Tavakolan [58] stated that the traditional evaluation method is unsuitable for FMEA analysis. Probabilities of occurrences are hard to evaluate with precise numbers. Therefore, the authors proposed using fuzzy numbers to solve ambiguities of the traditional FMEA approach. Therefore, FMEA techniques were combined with the FTOPSIS method in this study. In the second FGD session, the linguistic variables below were used (see Table 2). The used linguistic variables should be modified according to the study purpose [57,59]. Therefore, the interviews were conducted with four experts who have experience on KM applications and risk management. The expert profiles are given in Table A3 (Appendix A). The interviews were made between first and second FGDs. The used questionnaire in the interviews consisted of three parts. In the first part, the descriptive information about experts were asked. In the second part, the aim of the questionnaire and the example taken from [57] were presented to experts. Lastly, their views were asked. However, the experts approved that the example taken from [57] could be used for the evaluation of KM risks. Therefore, the linguistic variables taken from [57] were used in the second FGD.

Table 2. Linguistic variables used in FTOPSIS analysis [57,59].

Linguistic Variable	Probability of Occurrence	Severity of Consequences			Control Number
		Time of Delay Compared to Completion Date	Cost Increase Compared to Estimated Cost	Quality of Constructed Project	
Extremely high	Highly likely (>80%)	>20%	>40%	The uselessness of the entire/part of the project	Incapable of identifying/controlling a risk event before/after occurrence
High	Likely (50%< and ≤80%)	10%< and ≤20%	20%< and ≤40%	The quality decrease is conclusive	Low chance of identifying/controlling a risk event before/after the occurrence
Medium	Less likely (10%< and ≤50%)	5%< and ≤10%	10%< and ≤20%	Quality decrease required approval	Medium chance to identify/control a risk event before/after the occurrence
Low	Unlikely (5%< and ≤10%)	≤5%	≤10%	Quality decrease unimportant	High chance to identify/control a risk event before/after the occurrence
Very Low	Very unlikely (≤5%)	On time	No extra cost	Acceptable	Capable of identifying/controlling a risk event before/after the occurrence

3.3.2. Fuzzy Techniques for Order Performance by Similarity to Ideal Solution (TOPSIS)

Multi-Criteria Decision Making (MCDM) methods are intensely used in many areas, such as Economics, Social Sciences, and Engineering. Generally, MCDM methods are applied to problems in which "multiple objectives or multiple criteria conflict with each other". The analysis results guide decision-makers to make informed decisions according to the priorities [60].

Decision-making is made under some constraints, aims, and ambiguous conditions. Therefore, fuzzy theory considered incomplete, uncertain knowledge and information, and was combined with MCDM methods. Normally, in non-fuzzy MCDM methods, natural language is used in evaluating criteria or alternatives. However, the natural language is not clear. Also, subjective assessments given by experts include uncertainty [60].

The TOPSIS method was discovered by Hwang and Yoon. In this method, the alternatives are evaluated against conflicting criteria. The most important alternative is chosen according to "the shortest distance to the positive ideal solution and the farthest distance to the negative ideal solution" [60]. In the standard TOPSIS method, precise ratings and weights of criteria are used. However, it is impractical due to the nature of judgement and preferences given under vagueness. Therefore, fuzzy sets are proposed using linguistic variables [61]. After collecting data with linguistic variables, data sets are changed with their corresponding fuzzy sets. Triangular fuzzy numbers are expressed with *l (the smallest value)*, *m (the peak value)*, and *u (the largest value)*. If there is more than one expert, the aggregation of decision-makers' judgements is performed by arithmetic mean [61].

The Fuzzy TOPSIS (FTOPSIS) method has been used intensively in construction management literature. Risk management is one of the management areas in which TOPSIS is intensively used. For example, the TOPSIS method has been used in the selection of construction project selection and risk assessment [62], decommissioning risk management [63], risk quantifying in a supply chain [64], etc.

The FTOPSIS method steps are summarized below [61];

Step 1: After collecting expert views using linguistic variables in Table 3, a normalized fuzzy decision matrix is constructed by using Equations (1) and (2).

$$r_{ij} = \frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \text{ and } c_j^* = max_i c_{ij}(benefit\ criteria) \quad (1)$$

$$r_{ij} = \frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}} \text{ and } a_j^- = max_i a_{ij}(cost\ criteria) \quad (2)$$

Table 3. Fuzzy TOPSIS analysis results.

Factors	S^-	S*	CCi	Rank	Factors	S^-	S*	CCi	Rank
H1	1.82	3.63	0.334	6	O7	1.45	3.92	0.270	29
H2	1.55	3.83	0.288	27	O8	1.69	3.73	0.313	15
H3	1.61	3.77	0.299	22	O9	1.63	3.78	0.301	21
H4	1.75	3.68	0.323	8	O10	1.65	3.76	0.305	18
H5	1.84	3.62	0.337	5	O11	1.63	3.78	0.301	20
H6	1.75	3.69	0.322	9	O12	1.75	3.69	0.321	10
T1	1.42	3.93	0.266	31	O13	1.70	3.72	0.313	14
T2	1.58	3.83	0.292	25	O14	1.64	3.77	0.304	19
T3	1.71	3.71	0.315	13	O15	1.43	3.93	0.267	30
T4	1.52	3.85	0.283	28	O16	1.87	3.59	0.342	1
O1	1.66	3.76	0.307	17	O17	1.62	3.79	0.299	23
O2	1.77	3.68	0.324	7	O18	1.87	3.59	0.342	2
O3	1.73	3.70	0.319	12	O19	1.60	3.80	0.296	24
O4	1.56	3.83	0.289	26	O20	1.67	3.75	0.308	16
O5	1.87	3.59	0.342	3	O21	1.74	3.70	0.320	11
O6	1.86	3.61	0.341	4					

Step 2: The weighted normalize decision matrix is obtained by using Equation (2).

$$v_{ij} = w_j r_{ij} \quad (3)$$

where w_j stands for the weights of jth criterion.

Step 3: The positive ideal and negative ideal solutions are calculated by using Equations (3) and (4).

$$A^* = \{v_1^*, \cdots, v_n^*\} \quad (4)$$

$$A^- = \{v_1^-, \cdots, v_n^-\} \quad (5)$$

Step 4: Calculation of separation measures of alternatives is made via the vertex method. For the negative ideal alternative separation.

$$S_i^* = \sum_{j=1}^{n} d\left(v_{ij}, v_{ij}^*\right) \quad (6)$$

For the positive ideal alternative separation:

$$S_i^- = \sum_{j=1}^{n} d\left(v_{ij}, v_{ij}^-\right) \quad (7)$$

For the distance calculation:

$$d\left(\widetilde{m}, \widetilde{n}\right) = \sqrt{\frac{1}{3}\left[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - 3)^2\right]} \quad (8)$$

Step 5: The relative closeness to the ideal solution is calculated via Equation (9).

$$CCi = \frac{S_i^*}{S_i^* + S_i^-} \quad (9)$$

By following the abovementioned steps, Fuzzy TOPSIS analysis was conducted on the collected data from 20 experts. Analysis results are tabulated in Table 3.

The analysis results show that the most important risks are O16 "Financial risks", O18 "Time constraints to adapt KM in the projects", O5 "The use of obsolete/unreliable knowledge", O6 "Misinterpretation of knowledge or improper knowledge application", and H5 "Missing/inadequate competencies of organizational members", respectively. Furthermore, the least important risks were found as T1 "Cybercrime (hacking, threats of malicious software, e-mails, etc.)" and O15 "Political risks". The elaboration of the most and the least important risks will be performed in the discussion part. The following section will explain and validate the KM-related risk framework.

4. Validation of KM-Related Risks

KM-related risk framework was developed within the scope of the study. When the framework was developing, analysis results of Fuzzy TOPSIS were integrated into the framework. Figure 3 depicts the framework.

Four experts have been asked to evaluate the framework, and the developed framework has been validated by the experts [65]. The experts have either a PhD or MSc degree. They have at least ten years of experience, and they take a role in the top management. During the meeting, information about KM and KM-related risks was briefly presented. After that, the study steps and results were introduced. Also, the KM-related risk framework was shown. At the end of the presentation, three questions were asked to the experts. The questions and responses are summarized below.

Q1: "Is the developed framework comprehensive enough to consider and eliminate all KM-related risks?"

All participants confirmed that the developed framework is comprehensive to manage KM-related risks. The experts stated that, although they are crucial, KM-related risks fall behind other aspects of risk management, or even sometimes are entirely ignored.

Q2: "Do the analysis results reflect the importance of KM-related risks in the practice?"

The expert views showed that the construction companies have limited KM implementation attempts. Moreover, the experts stated that construction companies have limited resources, and the construction industry has a fragmented structure. In other words, they agreed that construction companies have an issue applying and keeping the accurate KM process and choosing the beneficial KM technologies. Additionally, they acknowledged that the importance sequence of KM risks is parallel to risks seen in the practice.

Q3: "Is the developed framework beneficial in terms of practice?"

The idea of the development of a KM-related risk framework was appreciated by all experts. They agreed that it would contribute to making risk management more comprehensive since KM-related risks are neglected. However, they proposed to use it at the planning stage. Moreover, they stated that identified risks related to human capital show the importance of the worker recruitment process. Within this context, they believed the framework would also support the adaptation of construction technologies.

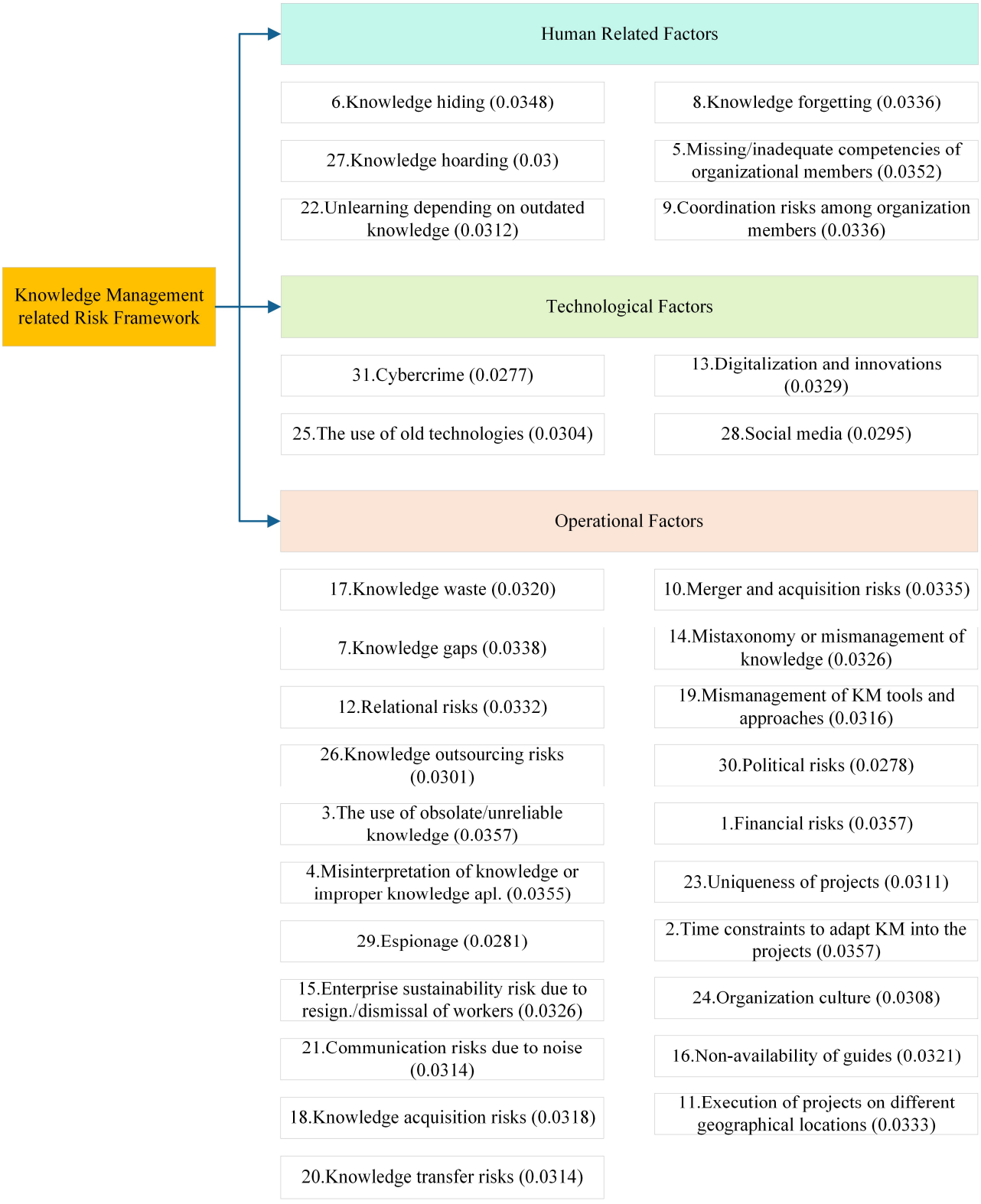


Figure 3. The KM-Related Risk Framework.

5. Discussion

KM-related risks are one of the most important and underestimated fields in risk management since knowledge is a key asset to keep construction companies progressing and developing. As abovementioned, KM helps to improve competitive advantages.

Therefore, this study aimed to name and determine the weights of KM-related risks and to develop a KM risk framework.

Analysis results showed that the financial risks are the most crucial factor hindering the functioning of KM in construction companies. The underlying reason behind this result is related to the necessity for resource allocation for KM, including financial investments, technology, and human capital. Therefore, construction companies should distribute their financial resources wisely to enable both flawless knowledge management and sustainable KM strategies. According to the findings of [66], a major cause of failure of KM applications are related to budgetary policies. Therefore, the practitioners should monitor and control the budgeted and actual expenses for KM activities as a KPI during the construction project [66]. Moreover, KM requires the support of digital technologies to make them more effective and efficient. Within this context, it requires assessing the return of investment and overseeing the costs related to implementation and benefits. For instance, the Building Information Model (BIM) is the most common and hot topic to enable project KM in construction companies. Therefore, the researchers developed a technology adaptation model for BIM specific to each country. These models aimed to facilitate BIM adaptation, enable a healthier KM process with BIM, and do not waste financial resources.

The second most significant risk was "Time constraints to adapt KM in the projects". Some features of projects are uniqueness, time constraints with the definition of the start and end point, and progressive elaboration. In construction projects, these features make KM more complex. While the uniqueness of construction projects affects the implementation of KM systems and processes into new projects, time constraint is another critical issue in the construction industry since the adaptation of new KM systems, technologies, and infrastructure and its familiarization demand time. Therefore, it creates pressure on KM implementation and discourages professionals. Moreover, Marinho and Couto [11] stated that continuous learning, a collaborative working environment, lessons learned, consulting, etc., can help to improve KM in the AEC industry. However, the transfer of intellectual assets to upcoming projects and the necessity of time for data records prevent effective KM. In KM applications, training activities can take considerable time. Therefore, to monitor the "Time constraints to adapt KM in the projects" risk, the practitioners can use time spent for knowledge training as a KPI [67]. Moreover, the worker productivity can be reduced while the KM activities are performed. Therefore, the effect of KM activities on worker productivity should be monitored as a KPI [68].

Depending on these issues in the AEC industry, the same mistakes are made repeatedly [4]. Therefore, systematic KM implementation is the most decisive remedy to overcome these issues. When the knowledge is generated, captured, and shared during the KM process, it helps to eliminate earlier mistakes. Parallel to the importance of data capturing, "The use of obsolete/unreliable knowledge" is the most significant third KM risk. The use of obsolete/unreliable knowledge will induce inaccurate decision-making. In construction projects, the decision-making process is continuous and requires exact and updated data resources. Otherwise, all information should be collected from the construction site or information sources whenever needed. Moreover, it will affect organizational effectiveness and strategies since it will cause a mistake in resource allocation (workforce, financial resources, equipment, et cetera). To monitor "The use of obsolete/unreliable knowledge" risk, the rate of up-to-date knowledge can be monitored as a KPI by practitioners [69].

Furthermore, "Misinterpretation of knowledge or improper knowledge application" was another crucial risk in the KM. The interpretation or analysis of data is especially vital to enable the proper application of knowledge. In misinterpreting knowledge, the lack of abilities and skills have undeniable effects. Therefore, construction companies should enhance collaborations with the universities to meet competent human resource needs. Moreover, excessive knowledge is another challenge in finding and analyzing the correct information sources [13]. Within this context, to enable a healthier KM process, first, the stakeholders need to decide which information should be managed and shared among project participants. Secondly, the information is processed to generate knowledge through

structuring, evaluation, presentation and dissemination of information. Finally, knowledge is stored, updated, and enhanced [4]. In construction companies, knowledge application accuracy rate can be measured as a KPI. Thus, the companies can obtain statistics related to their correct data analysis results and their application.

The analysis results also show that operational-related risks in KM come into prominence. These results can be related to giving less importance to the planning stage in the construction industry. In other words, planning-related issues accrued apparently when the project is executed.

6. Conclusions

Digitalization of industries and transactions of companies causes the generation of too much data. To manage data mass and transform it into actionable knowledge, companies should implement well-structured KM. However, the KM implementation level in the construction industry is extremely low due to the construction projects' nature. Moreover, construction companies are trying to adapt modern technologies to enable KM infrastructure. However, the construction companies are unfamiliar with the risks revealed during the KM. Additionally, there is not enough information to identify and manage KM risks. Therefore, this study aims to determine KM risks and develop a KM risk framework.

In the study, four steps of research methodology were applied; literature review, FGD to finalize literature findings, Fuzzy TOPSIS analysis, and expert review. The literature review analysis showed that there is no existing study on KM-related risks in the construction industry. Therefore, the existing studies about challenges and KM risks identified for other industries were used to identify KM-related risks. As a result of the analysis, thirty-one risks under three categories (human-related risks, technological risks and operational factors) were identified. Secondly, the comprehensiveness and adequacy of identified KM risks were determined with the use of the FGD technique. The outcome of the FGD indicated that the identified KM risks were enough, and experts did not want to add new risks. Thirdly, the Fuzzy TOPSIS method was applied to determine the importance level of KM-related risks. Within this context, twenty experts evaluated identified KM-related risks by considering their occurrences, severity, and control possibilities. The analysis results showed that O16 "Financial risks", O18 "Time constraints to adapt KM in the projects", O5 "The use of obsolete/unreliable knowledge", O6 "Misinterpretation of knowledge or improper knowledge application", and H5 "Missing/inadequate competencies of organizational members" are the most important five KM risks, respectively. The digitalization level of construction projects is lower in those other industries. Also, the dynamic and fragmented structure of construction projects and the construction industry's less educated human capital cause the industry to become more sensitive to financial resources. Moreover, the application and the creation of KM infrastructures require financial resources. Therefore, companies should show the utmost attention to financial risks to prevent destructive results. Furthermore, the construction project duration is limited to adapting KM processes and technologies. To manage this issue, the variability of workers, contractors or sub-contractors, and a well-defined KM structure and its technologies should be reviewed, and a stable structure should be set. Finally, the experts reviewed the analysis results and developed a framework. They discussed the adequacy and benefits of the developed framework and its similarity to the practice. The expert reviews showed that even though the framework is adequate and beneficial, the construction companies have limited knowledge to manage KM-related risks.

The developed framework is designed to address challenges and uncertainties that came with the integration of KM into the companies and the implementation of KM inherent in construction projects. This framework will improve the resilience of the construction industry to reduce the probability of adverse consequences. In terms of practice, the developed framework will enhance the decision-making process by showing the importance level of KM-related risks. Moreover, the expert review indicated that there is limited knowledge about KM risks. In other words, the framework will help to anticipate and mitigate

associated risks proactively. In terms of the theoretical contribution, the study aimed to improve risk management practices by adding a new perspective related to KM. Thus, the study will pave the way for a more comprehensive risk management system.

In this study, identified KM risks are generic risks (as a limitation), since this study is the first attempt to identify KM risks in the construction industry. Therefore, the identification and the investigation of importance level for KM risks can show variety for different types of construction projects and contract types. Therefore, the identification of KM risks by considering different types of construction projects and contract types can be performed as a further study. Moreover, the literature review findings showed that the identification of KM Key Performance Indicators (KPIs) can be performed.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to the confidentiality of experts.

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Appendix A

The descriptive information of participants in the 1st FGD session is given in Table A1.

Table A1. Expert profile (1st FGD session).

Expert ID	Personal Profession	Education	Years of Experience
E1	Technical Office Manager	Civil Engineer (MSc degree)	CI: 20 years. M: 8 years.
E2	Project Manager	Architect (MSc degree)	CI: 15 years. M: 5 years.
E3	Planning Manager	Civil Engineer (MSc degree)	CI: 18 years. M: 10 years.
E4	Project Manager	Civil Engineer (MSc degree)	CI: 14 years. M: 6 years.
E5	Technical Office Manager	Civil Engineer (MSc degree)	CI: 22 years. M: 14 years.
E6	Project Manager	Civil Engineer (MBA)	CI: 11 years. M: 5 years.
E7	Technical Office Manager	Civil Engineer (MSc degree)	CI: 15 years. M: 6 years.
E8	Project Manager	Architect (PhD Degree)	CI: 17 years. M: 8 years.
E9	Owner	Civil Engineer (MSc degree)	CI: 25 years. M: 15 years.
E10	Technical Office Manager	Architect (MSc degree)	CI: 13 years. M: 6 years.
E11	Academician	Civil Engineer (PhD Degree)	CI: 10 years. M: Not applicable.

CI: Construction industry, M: Managerial.

The descriptive information of participants in the 2nd FGD session is given in Table A2.

Table A2. Expert profile (2nd FGD session).

Expert ID	Personal Profession	Education	Years of Experience
E1	Technical Office Manager	Civil Engineer (MSc degree)	CI: 20 years. M: 8 years.
E2	Project Manager	Architect (MSc degree)	CI: 15 years. M: 5 years.
E3	Planning Manager	Civil Engineer (MSc degree)	CI: 18 years. M: 10 years.
E4	Project Manager	Civil Engineer (MSc degree)	CI: 14 years. M: 6 years.
E5	Technical Office Manager	Civil Engineer (MSc degree)	CI: 22 years. M: 14 years.
E6	Project Manager	Civil Engineer (MBA)	CI: 11 years. M: 5 years.
E7	Technical Office Manager	Civil Engineer (MSc degree)	CI: 15 years. M: 6 years.
E8	Project Manager	Architect (PhD Degree)	CI: 17 years. M: 8 years.
E9	Owner	Civil Engineer (MSc degree)	CI: 25 years. M: 15 years.
E10	Technical Office Manager	Architect (MSc degree)	CI: 13 years. M: 6 years.
E11	Academician	Civil Engineer (PhD Degree)	CI: 10 years. M: Not applicable.
E12	Planning Manager	Civil Engineer (MSc degree)	CI: 10 years. M: 5 years.

Table A2. *Cont.*

Expert ID	Personal Profession	Education	Years of Experience
E13	Planning Manager	Civil Engineer (MSc degree)	CI: 9 years. M: 5 years.
E14	Technical Office Manager	Civil Engineer (MSc degree)	CI: 12 years. M: 7 years.
E15	Academician	Civil Engineer (PhD Degree)	CI: 12 years. M: Not applicable.
E16	Owner	Civil Engineer (MBA)	CI: 22 years. M: 10 years.
E17	Technical Office Manager	Civil Engineer (MBA)	CI: 14 years. M: 6 years.
E18	Project Manager	Architect (MSc degree)	CI: 16 years. M: 10 years.
E19	Academician	Civil Engineer (PhD Degree)	CI: 7 years. M: Not applicable.
E20	Academician	Civil Engineer (PhD Degree)	CI: 8 years. M: Not applicable.

CI: Construction industry, M: Managerial.

The used linguistic variables should be modified according to the study purpose [57]. Therefore, the interviews were conducted with four experts. The expert profiles are given in Table A3.

Table A3. Expert profile (for the evaluation/modification of the linguistic variables).

Expert ID	Personal Profession	Education	Years of Experience
E1	Academician	Civil Engineer (PhD Degree)	CI: 10 years. M: Not applicable.
E2	Academician	Architect (PhD Degree)	CI: 15 years. M: Not applicable.
E3	Project Manager	Civil Engineer (MSc degree)	CI: 14 years. M: 6 years.
E4	Technical Office Manager	Civil Engineer (MSc degree)	CI: 22 years. M: 14 years.

CI: Construction industry, M: Managerial.

References

1. Dang, C.N.; Chih, Y.-Y.; Asce, A.M.; Long, L.-H.; Nguyen, L.D.; Asce, M. Project-Based A/E/C Firms' Knowledge Management Capability and Market Development Performance: Does Firm Size Matter. *J. Constr. Eng. Manag.* **2020**, *146*, 04020127. [CrossRef]
2. Yap, J.B.H.; Lock, A. Analysing the benefits, techniques, tools and challenges of knowledge management practices in the Malaysian construction SMEs. *J. Eng. Des. Technol.* **2017**, *15*, 803–825. [CrossRef]
3. Yap, J.B.H.; Lim, B.L.; Skitmore, M. Capitalising knowledge management (KM) for improving project delivery in construction. *Ain Shams Eng. J.* **2022**, *13*, 101790. [CrossRef]
4. Moshood, T.D.; Rotimi, F.E.; Rotimi, J.O.B. View of Knowledge Transfer And Management In The Construction Industry: Trends And Future Challenges. *Int. J. Constr. Supply Chain Manag.* **2013**, *12*, 72–102. Available online: https://ijcscm.com/menu-script/index.php/ijcscm/article/view/94/84 (accessed on 11 January 2023).
5. Yu, D.; Yang, J. Knowledge Management Research in the Construction Industry: A Review. *J. Knowl. Econ.* **2018**, *9*, 782–803. [CrossRef]
6. Yusof, M.N.; Yahaya, N.M.; Hassan, B.N.; Cheen, K.S. The Challenges In Implementing Knowledge Management Practices In Construction Industry. *Int. J. Eng. Adv. Technol.* **2023**, *8*, 86–90. Available online: https://www.ijeat.org/wp-content/uploads/papers/v8i5C/E10120585C19.pdf (accessed on 25 January 2023). [CrossRef]
7. Egwunatum, S.I.; Oboreh, J.C. Factors Limiting Knowledge Management among Construction Small and Medium Enterprises. *J. Eng. Proj. Prod. Manag.* **2022**, *12*, 25–38.
8. Deng, H.; Xu, Y.; Deng, Y.; Lin, J. Transforming knowledge management in the construction industry through information and communications technology: A 15-year review. *Autom. Constr.* **2022**, *142*, 104530. [CrossRef]
9. Perrott, B.E. A strategic risk approach to knowledge management. *Bus. Horiz.* **2007**, *50*, 523–533. [CrossRef]
10. Vaz-Serra, P.; Edwards, P. Addressing the knowledge management 'nightmare' for construction companies. *Constr. Innov.* **2021**, *21*, 300–320. [CrossRef]
11. Joaquim, A.; Marinho, C.; Couto, J. Contribution to improvement of knowledge management in the construction industry—Stakeholders' perspective on implementation in the largest construction companies. *Cogent Eng.* **2022**, *9*, 2132652. [CrossRef]
12. Zhu, F.; Hu, H.; Xu, F. Risk Causation Model to Capture and Transfer Knowledge In International Construction Projects. *J. Civ. Eng. Manag.* **2022**, *28*, 457–468. [CrossRef]
13. Durst, S.; Zieba, M. Mapping knowledge risks: Towards a better understanding of knowledge management. *Knowl. Manag. Res. Pract.* **2018**, *17*, 1538603. [CrossRef]
14. Bahamid, R.A.; Doh, S.I.; Khoiry, M.A.; Kassem, M.A.; Al-Sharafi, M.A. The Current Risk Management Practices and Knowledge in the Construction Industry. *Buildings* **2022**, *12*, 1016. [CrossRef]
15. Siraj, N.B.; Fayek, A.R. Risk Identification and Common Risks in Construction: Literature Review and Content Analysis. *J. Constr. Eng. Manag.* **2019**, *145*, 1685. [CrossRef]

16. Kanapeckiene, L.; Kaklauskas, A.; Zavadskas, E.K.; Seniut, M. Integrated knowledge management model and system for construction projects. *Eng. Appl. Artif. Intell.* **2010**, *23*, 1200–1215. [CrossRef]
17. Yepes, V.; López, S. Knowledge management in the construction industry: Current state of knowledge and future research. *J. Civ. Eng. Manag.* **2021**, *27*, 671–680. [CrossRef]
18. Castro Benavides, A.L.; Yepes, V.; Pellicer, E.; Cuéllar Reyes, Á.J. Knowledge management in the construction industry: State of the art and trends in research. *Rev. Constr.* **2012**, *11*, 1–10. Available online: https://riunet.upv.es/handle/10251/50653 (accessed on 21 February 2023).
19. Fong, P.S.W.; Kwok, C.W.C. Organizational Culture and Knowledge Management Success at Project and Organizational Levels in Contracting Firms. *J. Constr. Eng. Manag.* **2009**, *135*, 1348–1356. [CrossRef]
20. Tan, W. Knowledge management in the construction industry: The strategy of Singapore. *Int. J. Constr. Manag.* **2015**, *15*, 10–16. [CrossRef]
21. Forcada, N.; Fuertes, A.; Gangolells, M.; Casals, M.; MacArulla, M. Knowledge management perceptions in construction and design companies. *Autom. Constr.* **2013**, *29*, 83–91. [CrossRef]
22. Kivrak, S.; Arslan, G.; Dikmen, I.; Birgonul, M.T. Capturing Knowledge in Construction Projects: Knowledge Platform for Contractors. *J. Manag. Eng.* **2018**, *24*, 87–95. [CrossRef]
23. Yap, J.B.H.; Lim, B.L.; Skitmore, M.; Gray, J. Criticality of project knowledge and experience in the delivery of construction projects. *J. Eng. Des. Technol.* **2022**, *20*, 800–822. [CrossRef]
24. Abuezhayeh, S.W.; Ruddock, L.; Shehabat, I. Integration between knowledge management and business process management and its impact on the decision-making process in the construction sector: A case study of Jordan. *Constr. Innov.* **2022**, *22*, 987–1010. [CrossRef]
25. Loforte Ribeiro, F. Enhancing knowledge management in construction firms. *Constr. Innov.* **2009**, *9*, 268–284. [CrossRef]
26. Moshood, T.D.; Rotimi, F.E.; Rotimi, J.O.B. An Integrated Paradigm for Managing Efficient Knowledge Transfer: Towards a More Comprehensive Philosophy of Transferring Knowledge in the Construction Industry. *Constr. Econ. Build.* **2022**, *22*, 65–98. [CrossRef]
27. Aghimien, D.; Aigbavboa, C.O.; Gomes, F.; Thwala, W.D. Barriers to Knowledge Management in Small and Medium Construction Companies in South Africa. In Proceedings of the Creative Construction Conference 2019, Budapest, Hungary, 29 June–2 July 2019. [CrossRef]
28. Ferrada, X.; Serpell, A. Knowledge management and construction industry. *Rev. Constr.* **2009**, *8*, 46–58. Available online: https://scholar.google.com.tr/scholar?hl=de&as_sdt=0%2C5&q=Ximena+Ferrada%2CAlfredo+Serpell+%282009%29%2C+Knowledge+Management+and+the+Construction+Industry&btnG= (accessed on 3 September 2023).
29. Esmi, R.; Ennals, R. Knowledge management in construction companies in the UK. *AI Soc.* **2009**, *24*, 197–203. [CrossRef]
30. Guto, A.J.; Wasiu, A. Assessment of the Barriers to Knowledge Management Practices Among Construction Organizations in Abuja, Nigeria. 2020. Available online: https://www.researchgate.net/publication/359413669 (accessed on 21 February 2023).
31. Guribie, F.L.; Owusu-Manu, D.G.; Badu, E.; Edwards, D.J. Fuzzy synthetic evaluation of the systemic obstacles to personalizing knowledge flows within and across projects. *Constr. Innov.* **2022**, *23*, 546–566. [CrossRef]
32. Akhavan, P.; Zahedi, M.R.; Hosein, S.H. A conceptual framework to address barriers to knowledge management in project-based organizations. *Educ. Bus. Soc. Contemp. Middle East. Issues* **2014**, *7*, 98–119. [CrossRef]
33. Shokri-Ghasabeh PhoenixPM, M.; End, M.; Chileshe, N. Knowledge management Barriers to capturing lessons learned from Australian construction contractors perspective. *Constr. Innov.* **2014**, *14*, 1471–4175. [CrossRef]
34. Kokkaew, N.; Jokkaw, N.; Peansupap, V.; Wipulanusat, W. Impacts of human resource management and knowledge management on non-financial organizational performance: Evidence of Thai infrastructure construction firms. *Ain Shams Eng. J.* **2022**, *13*, 101750. [CrossRef]
35. Alhammadi, E.M.A.; Kasim, R.; Lohana, S. Knowledge Management Factors Affecting Construction Project Performance Model. *Int. J. Sustain. Constr. Eng. Technol.* **2022**, *13*, 149–158. Available online: https://publisher.uthm.edu.my/ojs/index.php/IJSCET/article/view/11231/4979 (accessed on 8 February 2023).
36. Sisirakumara Gunasekera, V.; Alam, S.; Choy Chong, S. Knowledge management critical success factors and project management performance outcomes in major construction organizations in Sri Lanka: A case study. *VINE J. Inf. Knowl. Manag. Syst.* **2018**, *48*, 537–558. [CrossRef]
37. Boamah, F.A.; Zhang, J.; Shehzad, M.U.; Sherani, D.; Wen, D. Exploring the impact of social capitals and knowledge creation on construction firms performance in the COVID-19 era. *J. Eng. Des. Technol.* **2022**. [CrossRef]
38. Ramadan, K.; Alchammari, A. The Relationship between Project Planning, Risk Management and Knowledge Integration on Project Success. *Acad. Strateg. Manag. J.* **2021**, *20*, 1939–6104.
39. Wibowo, M.A.; Waluyo, R.; Zhabrinna, Z. Investigation of the relationship between the knowledge management process and performance of a construction company: An empirical study. *Interdiscip. J. Inf. Knowl. Manag.* **2018**, *13*, 417–435. [CrossRef]
40. ElFar, A.; Elsaid, A.M.; Elsaid, E. How knowledge management implementation affects the performance of Egyptian construction companies. *J. Appl. Bus. Res.* **2017**, *33*, 409–438. [CrossRef]
41. Yusof, M.N.; Bakar, A.H.A.; Razak, N.A.; Tabassi, A.A. Knowledge management and growth performance in construction industry. *Adv. Environ. Biol.* **2015**, *9*, 189–193. Available online: https://go.gale.com/ps/i.do?p=AONE&sw=w&issn=19950756&v=2.1&it=r&id=GALE%7CA417473540&sid=googleScholar&linkaccess=fulltext (accessed on 21 February 2023).

42. Boamah, F.A.; Zhang, J.; Wen, D.; Sherani, M.; Hayat, A.; Horbanenko, O. Enablers of knowledge management: Practical research-based in the construction industry. *Int. J. Innov. Sci.* **2022**, *14*, 121–137. [CrossRef]
43. Othman, A.; Ismail, S.; Yahya, K.; Ahmad, M.H. Critical success factors in implementing knowledge management in consultant firms for the Malaysian construction industry. *Manag. Sci. Lett.* **2018**, *8*, 305–316. [CrossRef]
44. Yang, J.-B.; Yu, W.-D.; Tseng, J.C.R.; Chang, C.-S.; Chang, P.-L.; Wu, J.-W. Benefit Analysis of Knowledge Management System for Engineering Consulting Firms. *J. Manag. Eng.* **2013**, *30*, 05014005. [CrossRef]
45. Adi, W.A.; Hiyassat, M.; Lepkova, N. Business Strategy Development Model for Applying Knowledge Management in Construction. *J. Civ. Eng. Manag.* **2021**, *27*, 246–259. [CrossRef]
46. Hartono, B.; Sulistyo, S.R.; Kah, H.C.; Indarti, N. Knowledge Management Maturity and Performance in a Project Environment: Moderating Roles of Firm Size and Project Complexity. *J. Manag. Eng.* **2019**, *35*, 04019023. [CrossRef]
47. Author, C.; Khalifa, Z.A.; Jamaluddin, M.Y. Key Success Factors Affecting Knowledge Management Implementation in Construction Industry in Libya. *Aust. J. Basic Appl. Sci.* **2012**, *6*, 161–164.
48. Cheng, M.Y.; Peng, H.S.; Huang, C.M.; Chen, C.H. KM-oriented business process reengineering for construction firms. *Autom. Constr.* **2012**, *21*, 32–45. [CrossRef]
49. Kale, S.; Karaman, E.A. Evaluating the Knowledge Management Practices of Construction Firms by Using Importance–Comparative Performance Analysis Maps. *J. Constr. Eng. Manag.* **2011**, *137*, 1142–1152. [CrossRef]
50. Yun, G.; Shin, D.; Kim, H.; Lee, S. Knowledge-mapping model for construction project organizations. *J. Knowl. Manag.* **2011**, *15*, 528–548. [CrossRef]
51. Ahmad, H.; An, M. Knowledge management implementation in construction projects: A KM model for Knowledge Creation, Collection and Updating (KCCU). *Int. J. Proj. Organ. Manag.* **2008**, *11*, 133–166. [CrossRef]
52. Graham, P.; Nikolova, N.; Sankaran, S. Tension between leadership archetypes: Systematic review to inform construction research and practice. *J. Manag. Eng.* **2022**, *36*, 03119002. [CrossRef]
53. Yi, W.; Chan, A.P.C. Critical review of labor productivity research in construction journals. *J. Manag. Eng.* **2014**, *30*, 214–225. [CrossRef]
54. Sharif, S.M.F.; Naiding, Y.; Ur Rehman, A.; Farooq Sahibzada, U.; Kanwal, F. From partners' learning intent to knowledge leakage: The role of contract and trust. *Knowl. Manag. Res. Pract.* **2020**, *27*, 107–118. [CrossRef]
55. Yap, J.B.H.; Toh, H.M. Investigating the principal factors impacting knowledge management implementation in construction organizations. *J. Eng. Des. Technol.* **2020**, *18*, 55–69. [CrossRef]
56. Mishra, L. Focus Group Discussion in Qualitative Research. *TechnoLearn Int. J. Educ. Technol.* **2016**, *6*, 1–5. [CrossRef]
57. Ahmadi, M.; Behzadian, K.; Ardeshir, A.; Kapelan, Z. Comprehensive risk management using fuzzy FMEA and MCDA techniques in highway construction projects. *Vilnius Gedim. Tech. Univ.* **2017**, *23*, 300–310. [CrossRef]
58. Mohammadi, A.; Tavakolan, M. Construction project risk assessment using combined fuzzy and FMEA. In Proceedings of the 2013 Joint IFSA World Congress and NAFIPS Annual Meeting, IFSA/NAFIPS 2013, Edmonton, AB, Canada, 24–28 June 2013; pp. 232–237. [CrossRef]
59. PMI. Risk management. In *Project Management Body of Knowledge (Pmbok® Guide)*, 5th ed.; Project Management Institute: Singapore, 2013.
60. NĂdĂban, S.; Dzitac, S.; Dzitac, I. Fuzzy TOPSIS: A General View. *Procedia Comput. Sci.* **2016**, *91*, 823–831. [CrossRef]
61. Madi, E.N.; Garibaldi, J.M.; Wagner, C. An exploration of issues and limitations in current methods of TOPSIS and fuzzy TOPSIS. In Proceedings of the 2016 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE), Vancouver, BC, Canada, 24–29 July 2016; pp. 2098–2105. [CrossRef]
62. Taylan, O.; Bafail, A.O.; Abdulaal, R.M.S.; Kabli, M.R. Construction projects selection and risk assessment by fuzzy AHP and fuzzy TOPSIS methodologies. *Appl. Soft Comput.* **2014**, *17*, 105–116. [CrossRef]
63. Awodi, N.J.; Liu, Y.K.; Ayo-Imoru, R.M.; Ayodeji, A. Fuzzy TOPSIS-based risk assessment model for effective nuclear decommissioning risk management. *Prog. Nucl. Energy* **2023**, *155*, 104524. [CrossRef]
64. Samvedi, A.; Jain, V.; Chan, F.T.S. Quantifying risks in a supply chain through the integration of fuzzy AHP and fuzzy TOPSIS. *Int. J. Prod. Res.* **2013**, *51*, 2433–2442. [CrossRef]
65. Okudan, O.; Budayan, C.; Dikmen, I. A knowledge-based risk management tool for construction projects using case-based reasoning. *Expert Syst. Appl.* **2021**, *173*, 114776. [CrossRef]
66. Goodluck, I. Budgeting for knowledge management in organizations. *Chin. Librariansh. Int. Electron. J.* **2011**, *32*, 1–10.
67. Dave, B.; Koskela, L. Collaborative knowledge management—A construction case study. *Autom. Constr.* **2009**, *18*, 894–902. [CrossRef]
68. Demirdöğen, G.; Işık, Z.; Arayici, Y. Lean management framework for healthcare facilities integrating BIM, BEPS and big data analytics. *Sustainability* **2020**, *12*, 7061. [CrossRef]
69. Litvaj, I.; Stancekova, D. Decision-making, and their relation to the knowledge management, use of knowledge management in decision-making. *Procedia Econ. Financ.* **2015**, *23*, 467–472. [CrossRef]

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