sustainability

Article

Developing an MCDM Model for the Benefits, Opportunities, Costs and Risks of BIM Adoption

Seyed Mohammad Hossein Zakeri [1,*], Sanaz Tabatabaee [2], Syuhaida Ismail [2,3], Amir Mahdiyar [4,*] and Mohammad Hussaini Wahab [2]

1 Department of Architecture, School of Art and Architecture, Shiraz University, Shiraz 71946-84334, Iran
2 Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia, Kuala Lumpur 54100, Malaysia
3 Maritime Institute of Malaysia, Kuala Lumpur 50450, Malaysia
4 School of Housing, Building and Planning, Universiti Sains Malaysia, Penang 11800, Malaysia
* Correspondence: zakeri@shirazu.ac.ir (S.M.H.Z.); amirmahdiyar@usm.my (A.M.)

Abstract: Building information modeling (BIM) offers various deterministic and uncertain benefits and costs. Although there are similarities between such costs and benefits in developed and developing countries, these factors should be analyzed carefully for each region/country due to differences in economic and technical status as well as available policies and regulations. Numerous studies have demonstrated the benefits and shortcomings of BIM adoption around the globe; however, there is scarce comprehensive research focusing on Iran with unique financial circumstances. The aim of this research is to investigate the benefits, opportunities, costs and risks (BOCRs) offered by BIM implementation in Iran as a developing country with high potential in but less adoption of BIM in construction projects. After identifying the BOCRs of BIM adoption from the literature, the Interval-Valued Fuzzy Delphi Method was used to identify the BOCRs while a novel multi-criteria decision-making approach (i.e., fuzzy parsimonious analytic hierarchy process) was employed to analyze BOCRs, respectively. The results showed that 4 out of 46 BOCRs gathered from the literature were not significant for Iran and should be omitted from further analysis, while one cost factor was added to the list. Also, it was revealed that "Facilitates project communication among stakeholders", "Integrating life-cycle assessment dimensions to the decision-making process", "Cost/efforts required to personnel training" and "Lack of national standard, procedures and guidelines" were the most significant BOCRs, respectively. These findings contributed to filling the research gap in BIM adoption in Iran using a novel methodology that provides deep insights into BIM adoption for practitioners and can be used as a basis for developing theoretical and conceptual research frameworks. The findings of this study are built upon the opinions of experts within the context of Iran and should be considered as a snapshot of the BOCRs of the adoption of BIM in Iranian construction projects while these are not futureproofed.

Keywords: construction management; building information modeling; multi-criteria decision-making; parsimonious approach

Citation: Zakeri, S.M.H.; Tabatabaee, S.; Ismail, S.; Mahdiyar, A.; Wahab, M.H. Developing an MCDM Model for the Benefits, Opportunities, Costs and Risks of BIM Adoption. *Sustainability* **2023**, *15*, 4035. https://doi.org/10.3390/su15054035

Academic Editor: Samad Sepasgozar

Received: 19 December 2022
Revised: 16 February 2023
Accepted: 19 February 2023
Published: 22 February 2023

1. Introduction

The use of building information modeling (BIM) in various stages of construction projects has been a common approach for at least more than a decade in developed and also developing countries due to the myriad benefits offered to enhance the performance of projects [1]. Building information modeling as a collaborative methodology is adopted for improving the scheduling, cost management, sustainability and even safety performance of construction projects [2], and all its benefits have been widely discussed in the existing body of knowledge [3–5]. In addition, BIM has been employed for model and framework development using mathematical-based models (e.g., [6]) as well as other digital technologies such as virtual reality and augmented reality (e.g., [7]). However, the challenges and costs involved in BIM implementation in each type of construction project hinder its adoption [1], especially in developing countries.

Iran has a unique socioeconomic situation [8]; this has been explained by the high inflation rate, political conditions during construction projects and the various effects of sanctions on the construction industry [9], which have resulted in several issues such as increased estimated costs, limited access to technology, software, etc. The status of BIM adoption in Iran is still in infancy stage, while the guidelines for BIM adoption have been developed recently to mandate BIM adoption in large-scale construction projects. Some BIM-related research has been conducted in different areas of construction management in Iran, such as 5D BIM [8], energy consumption and cost trade-off [10] and manufacturing and maintenance [11]. Nevertheless, there remains a lack of comprehensive research on the benefits, opportunities, costs and risks (BOCRs) offered by BIM in the Iranian construction industry. Having a holistic understanding of all BOCRs and their relevant importance considering the contextual settings of Iran is crucial for achieving higher BIM adoption. This would consequently lead to the betterment of all aspects of future projects (e.g., cost management, sustainability, safety, etc.). As a result, two research questions are answered in this research: (1) What are the relevant BOCRs of BIM adoption in Iran?; and (2) How significant is each BOCR in its respective category?

To fill the above-mentioned gap and answer the research questions, this research aims to identify and analyze the BOCRs of BIM adoption in Iran using two hybrid fuzzy-based methods, namely, the Interval-Valued Fuzzy Delphi Method (IVFDM) and the Fuzzy Parsimonious Analytic Hierarchy Process (FPAHP). In addition to the benefits and costs associated with BIM adoption, there are also some uncertain positive (opportunity) and negative (risk) issues that should be considered to ensure the success of projects using BIM. It is notable to mention that, for the purpose of this research, 'opportunity' refers to any potential benefit that may or may not be gained by employing BIM considering the various aspects of a certain project (i.e., nature, scale, location, etc.). Similarly, a 'risk' is considered as any potential cost associated with the employment of BIM that may or may not occur subject to the specific characteristics of a project (see [12] for similar definitions). The contribution of the present research is threefold. First, it addresses the existing literature gap by holistically investigating all BOCRs within the context of Iran. Second, the adopted methodology requires considerably less time and effort from experts while producing valid and accurate results. Finally, identifying the importance of BOCRs provides valuable insights for decision-makers and assists them in formulating appropriate solutions for overcoming costs and risks and taking advantage of benefits and opportunities.

The remainder of this paper is organized as follows. Section 2 presents the literature on the BOCRs of BIM adoption in construction projects. Section 3 demonstrates the research methodology and how the objectives of the research are achieved. Section 4 illustrates and discusses the research findings, and finally, the study is concluded in Section 5.

2. Literature Review

Technology adoption refers to the process through which individuals, organizations, or societies accept and integrate new technologies into their projects and systems. The decision to accept or reject a new technology has been a challenge for decades and many researchers have provided solutions and assisted decision-makers. One of the most widely used theoretical frameworks to explain technology adoption is developed by Davis [13], in which usefulness and ease of use are perceived as the primary factors for technology adoption. In addition, research carried out by Alalwan et al. [14] highlighted the role of trust, perceived risk and social influence in shaping individuals' attitudes and behaviors toward adopting new technologies. Mitropoulos and Tatum [15] explored how managers in contractor organizations adopt new technologies and focus on decision-making processes, factors affecting them and strategies for managing uncertainty. Sepasgozar [16] developed a multi-stage framework for technology adoption to enhance the understanding of the decision-making process in the construction industry towards making informed decisions. In other research, Arayici et al. [17] examined the process of BIM adoption in lean architectural practice and concluded that when it comes to the success of the project in BIM adoption, the focus should not be mostly on technology, while people, process and management play considerable roles. As a result, in this research, all aspects of BIM (as a collaborative methodology and process supported by technology) adoption are considered in reviewing the literature and the identification of BOCRs in BIM adoption.

2.1. Benefits

There are numerous benefits associated with BIM adoption that have been reported in the existing literature [4,18]. These benefits are concerned with three main aspects: technology [19], workflow process [20] and people [21,22]. When it comes to the technological aspect, there are various benefits relating to the design stage. For instance, the usage of BIM allows for enhanced 3D modeling and visualization [23], early design stage energy modeling and analysis [24], better error detection (i.e., using a clash detection technique that illustrates which components of the design are interfering with one another), the identification of unsafe areas and/or incorporated design elements, as well as significantly improving the cost estimation accuracy [19].

Enhancing access to information relating to design components and supporting multidisciplinary workflow significantly improves the decision-making involved within the workflow process [20], easier project scheduling and planning [25], as well as the integration of safety simulations that enhance site management [18]. Additionally, it has been reported that BIM adoption considerably reduces unnecessary costs and delays (10% of contract value) while eliminating up to 40% of the unbudgeted change throughout the project [19]. Finally, when it comes to the benefits concerning people, BIM adoption facilitates a better understanding of the project through the improved communication and awareness of all stakeholders involved, which not only eases the coordination among parties but also allows for a more efficient design process [18,22].

2.2. Opportunities

The opportunities associated with BIM adoption are primarily related to its potential to further improve the decision-making process, as well as its potential positive implications in the realization of the Sustainable Development Goals (SDGs) [26]. One of the main decision-making-related opportunities associated with BIM adoption is that it can increase the quality of work (in terms of accuracy and reliability considering BIM's benefits in reducing errors) [18] while decreasing the overall required time. In fact, the literature suggests that the adoption of BIM can provide close to 7% savings in the overall time of the project [19] as well as savings in the overall cost [18]. This is particularly important for large-scale projects involving numerous stakeholders and hundreds of thousands of manhours. Additionally, since all stakeholders can have access to accurate and reliable information and can easily communicate through all types of simplified BIM-based tools [27], the chances of conflicts are further reduced [21]. From a technical point of view, the integration of Life Cycle Assessment (LCA) quantitative predictions within BIM could further assist in making quick yet well-informed decisions [20]. Moreover, the usage of 3D visualization can amplify workers' understanding of the design, safety concerns and increase their productivity [19].

Building information modeling adoption also provides a series of opportunities related to achieving SDGs. For instance, it paves the way for advancing prefabrication practices within the construction industry and conducting detailed energy simulations supporting the creation of more energy-efficient buildings [22,24]. Furthermore, BIM adoption also helps in the realization of lean construction principles, as these two have parallel functionalities [28]. Consequently, such opportunities would eventually assist in lowering global warming considering the significant contribution of the construction industry towards it [20]. The identified opportunities of BIM adoption in this paper could be related to several SDGs, especially SDGs 11 (sustainable cities and communities) and 12 (responsible consumption and production).

2.3. Costs

The costs associated with BIM adoption primarily revolve around initial and subsequent software and hardware costs, training, as well as maintaining databases and other required resources (i.e., models, files, documents, etc.) [29]. When it comes to adopting BIM, while the immediate cost consists of acquiring BIM-related software and the required hardware [21], nevertheless, not having the trained staff would render its adoption impractical. Therefore, adopting BIM requires significant planning, appropriate company-wide training and puts a huge financial load on a company [30]. Furthermore, there are ensuing lifecycle costs associated with maintaining the BIM-related software and hardware, as well as databases of existing projects, models and documents [21]. It is notable to mention that stakeholders are also unassured about the return-on-investment (ROI) of such a huge investment and the literature suggests there is still a great lack of information in this regard [31].

2.4. Risks

The risks of BIM adoption are concerned with three main aspects: data processing, standardization, as well as people, which are discussed in detail. In terms of data processing, one of the most important risks is software compatibility issues, which affect the seamless transmission of information to all stakeholders involved [20,29]. Additionally, when BIM models are accessed through varying software adopted by different stakeholders, the process often requires the conversion of data (due to the lack of interoperability), which significantly increases the chances of data loss [32]. On the other hand, managing and handling large datasets (consisting of model sharing, viewing, sorting, etc.) is regarded as another risk of adopting BIM, especially considering the frequent updates these files receive from all involved parties. Finally, security concerns regarding the potential leakage of information (the significance of which varies depending on the nature, scale, detail and specifications of projects that a firm is involved in) are reported as other risks associated with BIM adoption [29].

When it comes to standardization, the lack of available information and studies about construction projects adopting BIM is regarded as a risk within the literature [29]. In addition, as mentioned earlier, the adoption of BIM requires a substantial transformation in the management process and practices, and the lack of information about the nature of this required change within an organization renders it an important risk [21]. This also applies to uncertainties pertaining to legal liabilities such as data ownership and intellectual property rights (IPRs), settlement mechanisms for disputes, insurance policies, standard contract formats, as well as other topics that are currently being studied [32,33]. There is also a lack of standardization (particularly national ones that govern BIM procedures, activities and deliverables) from local authorities [27,29].

Finally, some of the risks of BIM adoption associated with people are the lack of or an insufficient number of experienced and skilled staff within firms, the increased workload on staff due to the additional time and efforts required, as well as difficulties in the transition from traditional workflows to BIM, particularly the file management aspect of it [29]. Furthermore, the multidisciplinary nature of BIM requires seamless collaboration among stakeholders and team members. Nevertheless, one of the risks mentioned in the literature is with respect to improper coordination (both within teams and within the industry as a whole) such as low level of information sharing [29]. This could potentially lead to shifting blame among stakeholders, since the responsibilities are not clear and transparent [34,35]. Finally, there is the issue of resistance to change from other stakeholders involved, which renders BIM adoption a risky approach [32]. The comprehensive list of the BOCRs derived from the existing literature is shown in Table 1.

Table 1. List of BOCRs of BIM adoption.

BOCR	Factors	Sub-Factors	Code	References
Benefits	Technology	Detailed 3D simulation and visualisation	B1.1	[23]
		Design error/clash detection	B1.2	[19]
		Detection of unsafe areas at the construction site	B1.3	[19]
		Energy modeling at the primary stages of the project	B1.4	[24]
		Increased quantity take off/cost estimation accuracy	B1.5	[36]
	Workflow Process	Improved project planning, scheduling and sequencing	B2.1	[25]
		Enhanced site management	B2.2	[18,19]
		Refined/integrated project information and knowledge management	B2.3	[27]
		Reduced rework and elimination of unbudgeted change	B2.4	[19]
		Saved construction costs and potential delays	B2.5	[27]
	People	Improved stakeholders' understanding of the project scope	B3.1	[18,21]
		Facilitates project communication among stakeholders	B3.2	[21,22]
Opportunities	Decision-making	Improved construction communication through utilising BIM dimensions	O1.1	[19,20]
		Supporting collaborative work within a multidisciplinary team	O1.2	[24]
		Reduced conflicts in the project	O1.3	[21]
		Improved labour productivity	O1.4	[19]
		Enhanced engineering design quality	O1.5	[19]
		Integrating LCA dimensions into the decision-making process	O1.6	[24,37]
		Reduction in overall project time	O1.7	[19]
		Reduced construction costs by minimizing the wastage of materials	O1.8	[19,22]
	Sustainability performance	Advancing prefabrication practice	O2.1	[22]
		Decide on the energy-efficient building by conducting detailed energy analysis	O2.2	[20]
		Decreasing global warming potential of building	O2.3	[20]
		Achieve sustainable and lean construction practice	O2.4	[27]
Costs	Initial monetary issues	High capital cost	C1.1	[27,29]
		Costs required to upgrade BIM operation hardware	C1.2	[21,38]
		Costs/efforts required to purchase BIM software and link information from other sources	C1.3	[21]
		Cost/efforts required for personnel training	C1.4	[38]
	Lifecycle monetary issues	Costs/efforts required to maintain BIM models and central files	C2.1	[21]
		Costs/efforts required to create, annotate and refine project documentation	C2.2	[21]
		Lack of information on ROI of BIM projects	C2.3	[31,38]
Risks	Data processing	Lack of software capability	R1.1	[29]
		Inefficient data interoperability	R1.2	[32]
		Model management difficulties	R1.3	[29]
		Information security readjustment	R1.4	[27,29]
	Standardisation	Inadequate project experience	R2.1	[29]
		Restructuring the organisation's management process	R2.2	[38]
		Lack of national standards, procedures and guidelines	R2.3	[32,38]
		Unclear legal liability	R2.4	[32,33]
	People	Insufficient top management support/commitment	R3.1	[38]
		Lack of experienced and skilled personnel	R3.2	[29]
		Improper collaboration and coordination among stakeholders	R3.3	[29]
		Unclarified responsibilities	R3.4	[38]
		Inadequate stakeholders' awareness and acceptance	R3.5	[38,39]
		Increase in short-term workload	R3.6	[29]
		Workflow transition difficulties	R3.7	[29,38]

3. Methodology

As can be seen in Figure 1, in this research, two hybrid methods were used, namely, the Interval-Valued Fuzzy Delphi Method (IVFDM), and the Fuzzy Parsimonious Analytic Hierarchy Process (FPAHP)—hybrid methods are defined as the combination of methods and are developed to improve the efficiency of methods based on the requirements of the research and are used numerous times in the literature (e.g., [40]). The former is used to refine the applicable BOCRs to the adoption of BIM based on the context of the research while the latter method is employed to rank BOCR importance. As outlined in Section 1, the existing literature does not take into consideration all the BOCRs within the context of Iran. Thus, the employed methodology must rely on the opinion of local experts with relevant knowledge and experience in the field to assess the applicability of the identified BOCRs (which are gathered from various contexts) to the Iranian construction industry. In addition, a multi-criteria decision-making (MCDM) approach is necessary considering the high number of identified factors that must be prioritized. To this end, AHP has been vastly adopted in the existing literature since it helps to break complex problems into individual factors, yielding more accurate results. Having outlined the above, there are four primary benefits of employing this methodology. First, it provides an opportunity for local qualified experts to review the identified BOCRs and assess their relevance to the local context. Second, a pairwise comparison of the factors provides more accurate results. Third, the incorporation of the Fuzzy approach accounts for the uncertainties associated with experts' subjective opinions (both for IVFDM and FPAHP). Finally, considering the limited availability of experts, the high number of factors and the required cognitive effort, the employed methodology offers a more efficient data collection procedure. In the following sections, the advantages of these hybrid methods compared to conventional ones and suitability and application in this research are further discussed in detail with relevant references.

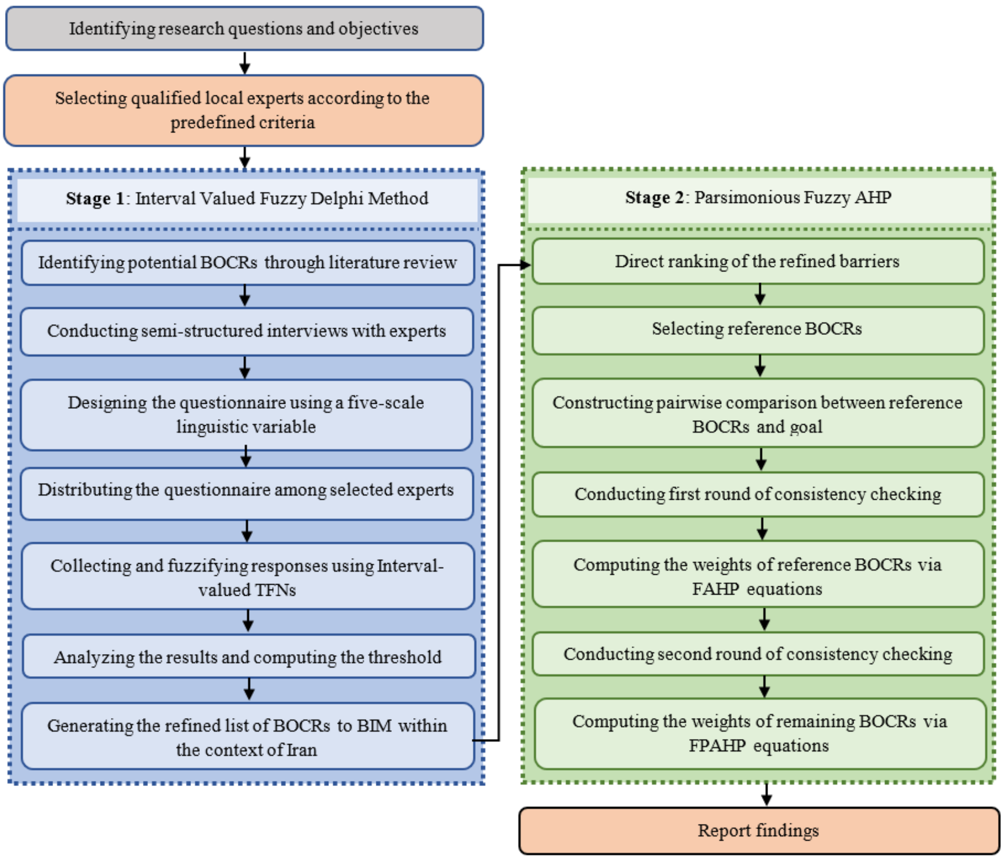

Figure 1. Research flowchart.

3.1. Selection of Experts

The methods exploited in this research rely primarily on input from qualified experts in the field. Studies within the construction industry often use non-probability sampling techniques [41], since having appropriate qualifications is proven to have a more significant impact than the mere quantity of experts involved [42]. Additionally, considering the nature of this study and the broad applications of BIM within the industry, much consideration should be given to having a pool of experts with varying backgrounds (i.e., architects, engineers, contractors, project managers, etc.). This would in turn help in forming a comprehensive understanding of all the different BOCRs that are applicable to each specific field while maintaining an accurate focus on the topic [43]. Additionally, Delphi studies are recommended to involve 8 to 15 experts [44,45]. As for the AHP studies, with consideration of the difficulties in identifying inconsistencies when the number of experts is large, Saaty and Ozdemir [46] recommended that the panel should not contain more than seven experts to minimize errors.

Considering the above, the present research opts for a purposive sampling approach for the selection of qualified experts based on a set of criteria supported by the existing literature and similar studies [45,47]. Accordingly, the two main criteria used when selecting experts are: (1) having at least five years of experience with BIM (i.e., the design, construction, or operation stages) and (2) possessing at least an undergraduate degree within the fields of architecture, building construction, engineering or project/construction management. As a result, in this study, 18 experts participated in different stages (IVFDM, FPAHP). Table 2 outlines their backgrounds as well as their involvement in different phases of this study.

Table 2. Background and involvement of experts in different phases of the study.

Position	No.	Degree	Years of Experience	Participation	
				IVFDM	FPAHP
Architect	1	MSc.	5–10	✓ *	
	2	Ph.D.	10–15	✓	✓
	3	Ph.D.	5–10	✓	✓
	4	Ph.D.	10–15	✓ *	
	5	Ph.D.	10–15	✓	✓
	6	MSc.	15–20	✓	
	7	MSc.	10–15	✓	
	8	MSc.	5–10	✓	✓
Engineer	1	Ph.D.	5–10	✓	
	2	Ph.D.	10–15	✓*	✓
	3	MSc.	10–15	✓	✓
	4	MSc.	15–20	✓	
	5	Ph.D.	10–15	✓	
	6	Ph.D.	5–10	✓	
Developer	1	BSc.	10–15	✓	
	2	MSc.	10–15	✓ *	✓
	3	MSc.	5–10	✓	✓
	4	BSc.	15–20	✓	

Note: * indicates the participation of an expert in a round of semi-structured interviews in IVFDM.

3.2. Interval-Valued Fuzzy Delphi Method

After an in-depth review of the literature and the identification of the potential BOCRs of BIM adoption, the first step is to systematically refine these items according to the contextual settings of Iran. To achieve this, an IVFDM is employed. The Delphi technique was initially developed by Dalkey and Helmer [48] as a consensus-making approach that relies on experts' opinions. Nevertheless, over the years it has been modified and hybridized with other approaches (e.g., Shah et al. [49]; Gunduz and Elsherbeny [50]) to address its common shortcomings such as not being able to add new factors to the existing pool, experts' reluctance to continue participation in all rounds and the vagueness of experts' subjective input [51,52]). To this end, the integration of Fuzzy approaches assists in overcoming the weaknesses of the traditional Delphi approach and better reflecting the vagueness associated with experts' subjective opinions [47]. Additionally, following similar Delphi studies (e.g., [53,54]), through the integration of a round of semi-structured interviews with qualified local experts representing academia and industry, any other potential BOCRs that may have been overlooked in the literature—or are unique to the context of Iran—are also identified and added to the list of BOCRs. Subsequently, a questionnaire is designed and experts' opinions are obtained and analyzed following the calculation process adopted from [55] using interval-valued triangular fuzzy numbers (IVTFN). Finally, and through the calculation of a threshold, BOCRs that are not significant in the context are excluded from further analysis. A complete step-by-step application of this method is as follows.

Step 1. Identifying potential BOCRs of BIM through the literature review and conducting a round of semi-structured interviews with qualified local experts in order to identify any other item that may have been overlooked or does not exist in the literature.

Step 2. Designing the questionnaire based on the semi-structured interview results and distributing it among the selected experts. The experts are asked to determine the significance of each BOCR in view of the contextual settings of Iran, using the linguistic variables (very low to very high) outlined in Table 3.

Table 3. Linguistic scales relative to IVTFNs.

Linguistic Variables	IVTFNs
Very low	((0.1, 0.1); 0.1; (0.2, 0.25))
Low	((0.15, 0.2); 0.3; (0.4, 0.45))
Medium	((0.35, 0.4); 0.5; (0.6, 0.65))
High	((0.55, 0.6); 0.7; (0.8, 0.85))
Very high	((0.75, 0.8); 0.9; (0.9, 0.90))

Step 3. The experts' input is then collected and transformed into IVTFNs. These are then analyzed using Equations (1)–(4) to obtain the fuzzy weights for each BOCR:

Let the assessment value of factor j provided by expert i in the pool of n experts be $\widetilde{A}_{inv} = [(l_2, l_1), m_2, (u_2, u_1)]$, and for $i = 1, 2, 3, \ldots, n$, and $j = 1, 2, 3, \ldots, m$. Thus, the following can be achieved:

$$\widetilde{A}_{invj} = \left[(l_2,\ l_1)_j,\ m_{2j}, (u_1,\ u_2)_j\right] \tag{1}$$

$$(l_2,\ l_1)_j = \left\{\min\ (l_2,\ l_1)_{ij}\right\} \tag{2}$$

$$m_{2j} = \frac{1}{n}\sum\nolimits_{i=1}^{n} m_{2ij} \tag{3}$$

$$(u_1,\ u_1)_j = \text{Max}\ \left\{(u_1,\ u_1)_{ij}\right\} \tag{4}$$

where $\widetilde{A}_{invj}$, is the interval-valued fuzzy weighting of factor j, $(l_2,\ l_1)_j$, is the minimum, m_{2j}, is the mean and $(u_1,\ u_1)_j$ is the maximum of all experts' input, respectively.

Step 4. Following the suggestions put forward by [52], and in order to defuzzify the obtained fuzzy weights ($\widetilde{A}_{invj}$) of each BOCR to a crisp value (S_j), the center of gravity approach (Equation (5)) is used.

$$S_j = \frac{l_{2j} + l_{1j} + m_{2j} + u_{1j} + u_{2j}}{5},\ \text{for } j = 1,\ 2,\ \ldots,\ m \quad (5)$$

Step 5. Lastly, once the crisp weights of all BOCRs are calculated, a threshold value (α) can be established (mean of all values in each category). Then, if $S_j \geq \alpha$, factor j is considered significant, and if $S_j < \alpha$, factor j is considered insignificant to the context of Iran. In other words, any BOCR that falls below the computed threshold (α) is excluded from further analysis and any BOCR that is above the threshold value can be included in the FPAHP stage.

3.3. Fuzzy Parsimonious Analytic Hierarchy Process

The AHP developed by Saaty (1980) is among the most employed MCDM tools within the construction industry [56]. This is due to its superiority in simplifying and decomposing complex problems into a hierarchy, pairwise comparison of factors, as well as quantifying the subjective input opinion of experts, all of which make solving these issues more efficient [57,58]. Nonetheless, when the problem on hand involves a large number of factors, the application of the standalone AHP is not practical due to the high number of required pairwise comparisons $(n\ (n-1)/2)$ resulting in a huge cognitive load on the experts involved [59]. Additionally, Saaty's 1–9 scale is not able to perfectly reflect the vagueness that is associated with subjective judgment and may result in uncertainties [60,61]. To overcome these weaknesses, numerous authors have put forward hybrid, improved, or modified methods such as the Cybernetic AHP [62], Express AHP [63] and Parsimonious AHP [59]. Among these, the parsimonious approach outperforms the rest since it significantly reduces the number of pairwise comparisons while still constructing actual pairwise comparisons (unlike cybernetic and Express AHP) and has two rounds of consistency checking ensuring the accuracy of findings [64]. In the parsimonious approach, instead of comparing all factors, the experts are requested to first directly rank all the factors and select references. Consequently, only reference factors are compared and the weights of all the other remaining factors are computed using parsimonious equations [59]. In addition, the hybridization of AHP with Fuzzy Sets, known more commonly as Fuzzy AHP (FAHP), has solved the uncertainties associated with the standalone AHP, and has been widely employed [40,65].

In view of the large number of BOCRs involved in the present research, the parsimonious approach is adopted and hybridized with FAHP. The benefits of exploiting this method are threefold: (1) reducing the required number of pairwise comparisons, which subsequently reduces the required time and cognitive efforts from experts involved, (2) eliminating the vagueness associated with experts' subjective opinions, therefore increasing the accuracy of findings and (3) ensuring that the results are consistent by providing two rounds of consistency checking. The following provide a step-by-step implementation of the FPAHP.

Step 1. Direct ranking and selection of reference BOCRs. In this step, experts are requested to directly rank the refined BOCRs—the ranking range could be determined by the experts and vary from one to another. Then, the number of reference factors is determined based on the number of factors in each category. Nevertheless, according to Abastante et al. [59], the following equation should be used to identify the required number of references:

$$n > \frac{r(r-1)}{2} + 3 \tag{6}$$

where n represents the total number of factors in each category of BOCR and the largest value for r is the number of reference BOCRs required. As suggested by Abastante et al. [59], reference BOCRs must be selected for each expert based on their individual direct ranking.

Step 2. Creating a pairwise comparison matrix between reference BOCRs with respect to the goal using the linguistic variables outlined in Table 4.

Table 4. The FAHP scale of importance [66].

Linguistic Variables	AHP Scale	FAHP Scale	
		TFNs	Reciprocal TFNs
Equally important	1	$(\frac{1}{2},1,3)$	$(\frac{1}{2},1,3)$
Moderately more important	3	(1,3,5)	$(\frac{1}{5},\frac{1}{3},1)$
Strongly more important	5	(3,5,7)	$(\frac{1}{7},\frac{1}{5},\frac{1}{3})$
Very strongly more important	7	(5,7,9)	$(\frac{1}{9},\frac{1}{7},\frac{1}{5})$
Extremely more important	9	(7,9,9)	$(\frac{1}{9},\frac{1}{9},\frac{1}{7})$

Step 3. The first round of consistency checking that is concerned with the consistency of pairwise comparison matrices is carried out utilizing the following equations [49]:

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{7}$$

$$CR = \frac{CI}{RI} \tag{8}$$

where λ_{max} is the highest value of eigenvalue, n denotes the matrix size, RI and CI are the random index and consistency index, respectively. The RI is considered based on the size of the matrix (i.e., 0.00, 0.00, 0.58, 0.90, 1.12, 1.24, 1.32, 1.41, 1.45 and 1.49 for matrix sizes 1–10, respectively [67]. According to Shah et al. [49], an acceptable consistency ratio is <0.1; otherwise, the experts are requested to amend their input.

Step 4. Computing the weight of reference BOCRs through the application of FAHP equations. To do so, matrix $Q = [q_{ij}]$, is created, where q_{ij} is the component of the comparison matrix, "i" represents the rows, "j" represents the column factors and r denotes the number of reference BOCRs. The linguistic values employed in the matrices are swapped with TFNs for analysis. Thus, a fuzzy comparison matrix, $Q' = [q'_{ij}]$, is made, where q'_{ij} is a TFN that is defined as: $q'_{ij} = (l_{ij}, m_{ij}, u_{ij})$, where l_{ij}, m_{ij}, u_{ij} represent the lower bound, modal and upper bound values for q'_{ij}, correspondingly. Then, to create the aggregation of l_{ij}, m_{ij}, u_{ij} of all BOCRs, the geometric mean (GM) of the values is computed and the matrix below is defined:

$$S'_{r\times 3} = \begin{bmatrix} l_{S'_{i1}} & m_{S'_{i2}} & u_{S'_{i3}} \\ \vdots & \vdots & \vdots \\ l_{S'_{r1}} & m_{S'_{r2}} & u_{S'_{r3}} \end{bmatrix}, i = 1,2,\ldots,r = \begin{bmatrix} \left(\prod_{j=1}^{r} l_{ij}\right)^{1/r} & \left(\prod_{j=1}^{r} m_{ij}\right)^{1/r} & \left(\prod_{j=1}^{r} u_{ij}\right)^{1/r} \\ \vdots & \vdots & \vdots \\ \left(\prod_{j=1}^{r} l_{ij}\right)^{1/r} & \left(\prod_{j=1}^{r} m_{ij}\right)^{1/r} & \left(\prod_{j=1}^{r} u_{ij}\right)^{1/r} \end{bmatrix} \tag{9}$$

It is notable to mention that the TFNs in the matrix S' must first be defuzzified into crisp values to calculate the weight of each reference BOCR. Thus, the sum of each column is calculated using:

$$G = [l_g,\ m_g, u_g] = \left[\sum_{i=1}^{r} l_{s'_{ij}}, \sum_{i=1}^{r} m_{s'_{ij}}, \sum_{i=1}^{r} u_{s'_{ij}}\right] \tag{10}$$

$$Y = [l_y,\ m_y, u_y] = \left[{l_g}^{-1},\ {m_g}^{-1}, {u_g}^{-1}\right] \tag{11}$$

Then, the l_y, m_y, and u_y are arranged in an ascending order and named as $Y1$, $Y2$ and $Y3$. Equations (12) and (13) are utilized to compute the local weights of reference BOCRs.

$$B_{r\times 3} = \begin{bmatrix} l_{B_{i1}} & m_{B_{i2}} & u_{B_{i3}} \\ \vdots & \vdots & \vdots \\ l_{B_{r1}} & m_{B_{r2}} & u_{B_{r3}} \end{bmatrix}, i = 1, 2, \ldots, r = \begin{bmatrix} \frac{l_{S'_{i1}}}{Y1} & \frac{m_{S'_{i2}}}{Y2} & \frac{u_{S'_{i3}}}{Y3} \\ \vdots & \vdots & \vdots \\ \frac{l_{S'_{r1}}}{Y1} & \frac{m_{S'_{r2}}}{Y2} & \frac{u_{S'_{r3}}}{Y3} \end{bmatrix} \tag{12}$$

$$C_{r\times 1} = \begin{bmatrix} \frac{l_{B_{i1}} + m_{B_{i2}} + u_{B_{i3}}}{3} \\ \vdots \\ \frac{l_{B_{r1}} + m_{B_{r2}} + u_{B_{r3}}}{3} \end{bmatrix} \tag{13}$$

In the last step, the weights in matrix C are normalized to obtain the normalized local weight of reference BOCRs.

Step 5. In this step, a second round of consistency checking is carried out. While the consistency of the experts' input is checked for reference BOCRs in Step 3, considering that the weights of the remaining BOCRs will be computed according to the direct rankings (Step 1) as well as the weights of reference BOCRs, it is important to conduct this round of consistency. In this regard, the responses are considered consistent if the order of ranking is the same between Step 1 and Step 4, or else these steps should be reevaluated by the experts to meet acceptable consistency. In other words, the experts can modify either their direct ranking (Step 1), or the pairwise comparison (Step 2), or both.

Step 6. Calculating the weights of all BOCRs once the consistency of the responses is confirmed. The local weights of all BOCRs are computed as follows:

$$W_b = W_a + \frac{W_c - W_a}{R_c - R_a}(R_b - R_a) \tag{14}$$

where b is the targeted BOCR (non-reference BOCR) and a and c are the reference BOCRs with the lower and higher values, W denotes the weight and R illustrates the direct ranking (determined in Step 1).

4. Results and Discussion

4.1. BOCRs of BIM Adoption in the Iranian Construction Industry

In order to identify the BOCRs of BIM, the comprehensive literature was reviewed and semi-structured interviews were conducted with experts in this field. Once the opinions of the experts were gathered, a questionnaire was developed and the experts were asked to rank the importance of each BOCR using the given linguistic scale (Table 3). After analyzing the responses using IVFDM (Equations (1)–(5)), 4 out of 46 BOCRs were rejected from consideration for further analysis, including "decreasing global warming potential of building", "cost/efforts required to personnel training", "costs/ efforts required to create, annotate and refine project documentation", and "lack of software capability". The BOCRs with higher defuzzification values than the threshold were accepted to be considered for further analysis. The threshold value was calculated as 0.66, according to Section 2.2, Step 5, and the status of the BOCRs' defuzzification values against the threshold is illustrated in Figure 2.

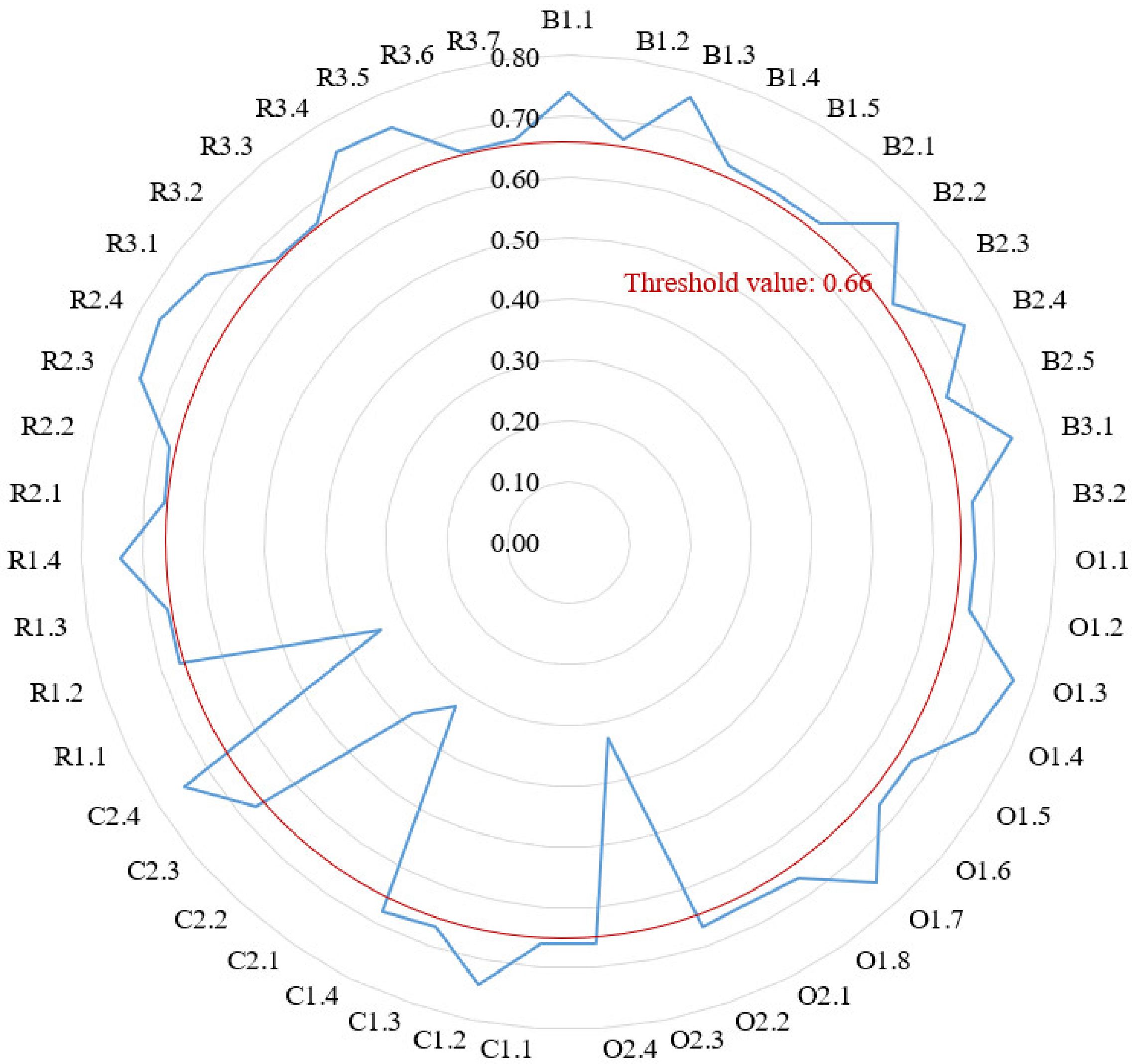

Figure 2. Defuzzification values of BOCRs—IVFDM results.

Moreover, as an outcome of semi-structured interviews, "increase in costs due to workflow changes" (C2.4) was added to the list as a cost factor. The C2.4 could be applicable not only to Iran but also to other countries, especially those countries with higher inflation rates. The inflation rate in Iran is higher than other developing countries due to its economic circumstances and it is expected that changes in workflow, which lead to an unexpected delay in performing construction activities, may influence the overall cost of the project significantly. Consequently, the experts believed that this should be added to the cost factors and analyzed in the next step of the research. The final results of the IVFDM analysis are shown in Table 5.

Table 5. Results of BOCR refinement and ranking.

Category	Factors	Code	IVFDM			FPAHP	
			Fuzzy Weight	Defuzzification Value	Decision	Weight	Rank
Benefits	Technology	B1.1	(0.55,0.60;0.75;0.90,0.90)	0.741	Accept	0.121	2
		B1.2	(0.35,0.40;0.78;0.90,0.90)	0.667	Accept	0.091	6
		B1.3	(0.55,0.60;0.84;0.90,0.90)	0.759	Accept	0.052	10
		B1.4	(0.35,0.40;0.81;0.90,0.90)	0.673	Accept	0.097	5
		B1.5	(0.35,0.40;0.78;0.90,0.90)	0.667	Accept	0.102	3

Table 5. *Cont.*

Category	Factors	Code	IVFDM			FPAHP	
			Fuzzy Weight	Defuzzification Value	Decision	Weight	Rank
Benefits	Workflow Process	B2.1	(0.35,0.40;0.78;0.90,0.90)	0.667	Accept	0.078	8
		B2.2	(0.55,0.60;0.81;0.90,0.90)	0.753	Accept	0.033	12
		B2.3	(0.35,0.40;0.75;0.90,0.90)	0.661	Accept	0.101	4
		B2.4	(0.55,0.60;0.75;0.90,0.90)	0.741	Accept	0.031	11
		B2.5	(0.35,0.40;0.77;0.90,0.90)	0.665	Accept	0.085	7
	People	B3.1	(0.55,0.60;0.78;0.90,0.90)	0.747	Accept	0.063	9
		B3.2	(0.35,0.40;0.78;0.90,0.90)	0.667	Accept	0.146	1
Opportunities	Decision-making	O1.1	(0.35,0.40;0.78;0.90,0.90)	0.667	Accept	0.062	9
		O1.2	(0.35,0.40;0.78;0.90,0.90)	0.667	Accept	0.094	4
		O1.3	(0.55,0.60;0.87;0.90,0.90)	0.764	Accept	0.039	11
		O1.4	(0.55,0.60;0.72;0.90,0.90)	0.736	Accept	0.071	8
		O1.5	(0.35,0.40;0.78;0.90,0.90)	0.667	Accept	0.086	7
		O1.6	(0.35,0.40;0.78;0.90,0.90)	0.667	Accept	0.152	1
		O1.7	(0.55,0.60;0.81;0.90,0.90)	0.753	Accept	0.093	5
		O1.8	(0.35,0.40;0.78;0.90,0.90)	0.667	Accept	0.134	2
	Sustainability performance	O2.1	(0.35,0.40;0.75;0.90,0.90)	0.661	Accept	0.117	3
		O2.2	(0.35,0.40;0.78;0.90,0.90)	0.667	Accept	0.091	6
		O2.3	(0.10,0.10;0.18;0.60,0.65)	0.327	Reject	-	-
		O2.4	(0.35,0.40;0.75;0.90,0.90)	0.661	Accept	0.061	10
Costs	Initial monetary issues	C1.1	(0.35,0.40;.075;0.90,0.90)	0.661	Accept	0.107	6
		C1.2	(0.55,0.60;0.75;0.90,0.90)	0.741	Accept	0.163	5
		C1.3	(0.35,0.40;0.78;0.90,0.90)	0.667	Accept	0.185	2
		C1.4	(0.35,0.40;0.84;0.90,0.90)	0.679	Accept	0.198	1
	Lifecycle monetary issues	C2.1	(0.10,0.10;0.18;0.60,0.65)	0.327	Reject	-	-
		C2.2	(0.15,0.20;0.30;0.60,0.65)	0.380	Reject	-	-
		C2.3	(0.35,0.40;0.81;0.90,0.90)	0.673	Accept	0.171	4
		C2.4	(0.55,0.60;0.78;0.90,0.90)	0.747	-	0.176	3
Risks	Data processing	R1.1	(0.10,0.10;0.24;0.60,0.65)	0.339	Reject	-	-
		R1.2	(0.35,0.40;0.78;0.90,0.90)	0.667	Accept	0.070	9
		R1.3	(0.35,0.40;0.78;0.90,0.90)	0.667	Accept	0.011	13
		R1.4	(0.55,0.60;0.72;0.90,0.90)	0.736	Accept	0.012	12
	Standardization	R2.1	(0.35,0.40;0.78;0.90,0.90)	0.667	Accept	0.088	5
		R2.2	(0.35,0.40;0.81;0.90,0.90)	0.673	Accept	0.087	6
		R2.3	(0.55,0.60;0.81;0.90,0.90)	0.753	Accept	0.136	1
		R2.4	(0.55,0.60;0.87;0.90,0.90)	0.764	Accept	0.077	7
	People	R3.1	(0.55,0.60;0.75;0.90,0.90)	0.741	Accept	0.105	4
		R3.2	(0.35,0.40;0.78;0.90,0.90)	0.667	Accept	0.114	3
		R3.3	(0.35,0.40;0.78;0.90,0.90)	0.667	Accept	0.010	14
		R3.4	(0.55,0.60;0.78;0.90,0.90)	0.747	Accept	0.027	11
		R3.5	(0.55,0.60;0.75;0.90,0.90)	0.741	Accept	0.127	2
		R3.6	(0.35,0.40;0.78;0.90,0.90)	0.667	Accept	0.065	10
		R3.7	(0.35,0.40;0.78;0.90,0.90)	0.667	Accept	0.071	8

4.2. Significance of BIM BOCRs

A FPAHP model was developed to analyze the importance of identified BOCRs. Each BOCR was ranked in its respective category based on the experts' opinions using the linguistic scale given in Table 4. The final weights and ranks of all BOCRs (average of all weights based on each expert's opinions) are shown in Table 5. It is worth mentioning that the consistencies of the responses were checked using Equations (7) and (8) and the range of consistency ratios is 0.01–0.05. Since all values are less than 0.1, the responses are considered consistent. As can be seen in Table 5, "Facilitates project communication among stakeholders", "Integrating LCA dimensions to the decision-making process", "cost/efforts required to personnel training", and "Lack of National standard, procedures and guidelines" are the most significant BOCRs, respectively.

4.2.1. Benefits and Opportunities

The findings of this research are supported by the literature. For instance, according to Table 5, the most important benefits of BIM adoption are B3.2 and B1.1, which is consistent with the findings reported by Chan et al. [13] and Röck et al. [19]. Since many construction projects in Iran are handled by engineers and consultants from different groups—either in small- or large-scale projects—communication among stakeholders including engineers and clients has always been a challenging task. This could be the main reason that B3.2 is ranked as the most important benefit of BIM implementation in construction projects in Iran. In addition to the challenges in communication, due to the ineffective communication between the engineers, many dispute cases have been caused due to the use of 2D or simple 3D plans and B1.1 is considered the second highly important benefit. In addition, the most significant opportunities that BIM adoption offer to construction projects in Iran have also been reported in studies conducted in other countries ([17,32]). Also, the outputs of much existing research (e.g., [57]) have shown that BIM adoption results in an increase in the efficiency of the project and more sustainable project management. This is in line with the results of this research, as O1.4 is ranked as the most significant opportunity, showing that the successful implementation of BIM could increase the productivity of workers. In addition, it was shown that O1.8, as the second most important opportunity, would result in a more sustainable built environment by reducing material wastage. It is notable to mention that while the results of this research indicate that all construction stakeholders believe in these positive effects in the Iranian context, due to various unexpected economic uncertainties/changes, especially as the result of sanctions, not all of them are expected to be exploited during the project execution. As a result, these factors have been listed as opportunities in this research.

4.2.2. Costs and Risks

When it comes to the risks of adopting BIM in the context of Iran, R3.2, R 3.5 and R2.3 were identified as the most significant ones, which is supported by the research conducted by Marefat et al. [58]. They (ibid) showed that the lack of well-trained personnel, governmental support and infrastructure were the most significant barriers to BIM adoption in 2017—the time their research was carried out—which is consistent with the findings of the current research. This consistency proves that despite the efforts undertaken by the government and stakeholders in the past five years, these barriers still exist; as a result, the Iranian governmental agencies have to investigate the reasons behind the lack of success in overcoming those barriers after quite a long time. There are, in fact, many good examples of government-driven approaches [59] for successful BIM adoption in developed countries such as Singapore and the UK.

In terms of R3.1, it was ranked as the fourth most important risk factor, which shows the importance of support from management in the success of BIM adoption. This factor was identified as one of the two most important ones in the review conducted by Meng et al. [60]. The identification of the most influential risk factors and the solutions to manage such factors is not easy as there might be different opinions among various construction stakeholders and in some cases they might not easily come to an agreement as discussed by Chieu et al. [61]. This indicates the importance of the risk management process in the success of BIM adoption as well as a strong need to identify, analyze and respond to the risks based on the collective opinions of all stakeholders.

In terms of the costs of BIM adoption, while the importance of each factor varies due to the differences in economic, technical and political situations, a clear consistency can be seen from the research conducted in other developing countries with the findings of this research. For instance, the study conducted by Olanrewaju et al. [62] in Nigeria showed that C1.4 and C1.3 are among the most influential costs for BIM adoption, while these have were ranked as the most influential ones in this research. In Turkey, the result of a study carried out by Ergen and Alshorafa [68], showed that the lack of trained personnel will significantly impact the cost of BIM adoption (in line with the findings of the current research), which indicates the existence of relationships among them. In addition, there is a new cost factor (C2.4) that has been added by the experts who contributed to this research and the findings showed that although it is not among the most significant cost factors, it is of importance and should be considered in the Iranian context due to its unique economic circumstances. This finding indicates that despite similarities in the literature, the existence and importance of all BOCRs should be investigated in each region/country to ensure their applicability in that context.

4.3. Validation

The results of this study present the importance of BOCRs in the construction industry in Iran using a novel fuzzy MCDM approach to fill the current research gap. To ensure the validity of the research methodology and its results, common elements of validation in construction research (i.e., face, construct, internal and external validity) [69] were considered. Since qualified experts contributed to this research (based on the discussed criteria in Section 3.1), it can be stated that the results are valid considering the face validity element. In terms of construct validity—which refers to making sure the ongoing research has achieved its objective(s) [70]—in this research, the findings of the research are considered to be valid as reliable data were collected; rigorous steps were followed in the methodology and the findings showed that the research objectives had been achieved successfully. It is notable that when it comes to internal and external validities, using purposive sampling as a non-probability sampling method limits the validation of the results [71]. It should be mentioned that there might be potential confounding variables that affect the results of this research due to using a non-probability sampling method, as a common limitation for studies using this type of sampling, and the conclusions of this research can be used merely for the considered BOCRs in Iran.

4.4. Implications

The present research has a number of academic and practical implications. First, it provides a comprehensive image concerning the BOCRs of BIM adoption derived from the existing literature, which can be used as a building block for future research. In addition, the findings of this research give academics a deep insight into the positive and negative points of BIM adoption in developing countries that can then be used either for further investigations or for developing conceptual frameworks. In addition, given the necessity of and the increase in BIM adoption in construction projects, the findings of this research help managers to have a clearer idea not only of the deterministic aspects of BIM adoption (costs and benefits) but also of uncertain aspects (opportunities and risks). Since the success of adopting technologies such as BIM in construction projects is achieved by exploiting opportunities and managing uncertainties, the findings of this research give hindsight to construction managers for the successful adoption of BIM in their projects. Finally, knowing the significance of each BOCR provides the construction industry stakeholders and policy-makers the possibility to consider and develop potential solutions to overcome—or at least diminish—various important risks and costs, while planning for utilizing potential opportunities and maximizing benefits.

5. Conclusions

This paper first reviewed the existing literature pool regarding the BOCRs of BIM adoption in construction projects and identified those BOCRs applicable to Iranian construction projects using IVFDM. Subsequently, the significance of the identified BOCRs was determined through the exploitation of the FPAHP method. The novelty of this research is twofold: first, the identification of a comprehensive list of BOCRs of BIM adoption in Iranian construction projects including 12 benefits, 11 opportunities, 6 costs and 14 risks; second, prioritizing those BOCRs within the context of a developing country using an efficient fuzzy-based MCDM approach, which is the first of its kind to the best of the authors' knowledge. It was concluded that among the myriad of BOCRs, "facilitates project communication among stakeholders", "integrating LCA dimensions to the decision-making process", "Cost/efforts required to personnel training", and "lack of national standard, procedures and guidelines" were the most significant benefits, opportunities, costs and risks in the Iranian construction industry, respectively.

Notwithstanding the contributions of the present research, there are certain limitations that must be taken into consideration. First, the findings of this study are built upon the opinions of experts within the context of Iran and should be considered as a snapshot of the BOCRs of the adoption of BIM in Iranian construction projects. In addition, while the research framework put forward is reproducible for other contexts and similar results are expected to be found in similar contexts, the findings of this research are not generalizable as a common limitation of employing purposive sampling techniques. It is also important to note that given the difference between the financial, technological and technical aspects in various countries and also the fast pace of technological advancements, the findings of this research are not future-proofed. Thus, the identified BOCRs should be reinvestigated to be used in other contexts, or by construction managers for specific projects. Thus, as a potential future direction, the authors call for the replication of this research in other contexts and conducting comparative studies. On the other hand, this research did not consider the relationship among BOCRs and thus, future research is advised to investigate the relationships among the identified BOCRs of the adoption of BIM in construction projects in varying contexts.

Author Contributions: Conceptualization: S.T.; Methodology: A.M. and S.T.; Software: S.T.; Formal analysis: S.T. and A.M.; Investigation: S.M.H.Z.; Resources: S.M.H.Z.; Data curation: S.M.H.Z.; Writing—original draft preparation: S.M.H.Z., S.T., A.M. and S.I.; Writing—review and editing: S.M.H.Z., S.T., A.M. and M.H.W.; Visualization: S.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research has been supported by the Research Management Centre of Universiti Teknologi Malaysia under cost center R.K130000.7113.06E35.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Durdyev, S.; Ashour, M.; Connelly, S.; Mahdiyar, A. Barriers to the Implementation of Building Information Modelling (BIM) for Facility Management. *J. Build. Eng.* **2021**, *46*, 103736. [CrossRef]
2. Tran, S.V.-T.; Nguyen, T.L.; Chi, H.-L.; Lee, D.; Park, C. Generative Planning for Construction Safety Surveillance Camera Installation in 4D BIM Environment. *Autom. Constr.* **2022**, *134*, 104103. [CrossRef]

3. Al-Ashmori, Y.Y.; Othman, I.; Rahmawati, Y.; Amran, Y.H.M.; Sabah, S.H.A.; Rafindadi, A.D.; Mikić, M. BIM Benefits and Its Influence on the BIM Implementation in Malaysia. *Ain Shams Eng. J.* **2020**, *11*, 1013–1019. [CrossRef]
4. Yang, J.-B.; Chou, H.-Y. Subjective Benefit Evaluation Model for Immature BIM-Enabled Stakeholders. *Autom. Constr.* **2019**, *106*, 102908. [CrossRef]
5. Zhou, Y.; Ding, L.; Rao, Y.; Luo, H.; Medjdoub, B.; Zhong, H. Formulating Project-Level Building Information Modeling Evaluation Framework from the Perspectives of Organizations: A Review. *Autom. Constr.* **2017**, *81*, 44–55. [CrossRef]
6. Sadeghifam, A.N.A.N.; Meynagh, M.M.M.M.; Tabatabaee, S.; Mahdiyar, A.; Memari, A.; Ismail, S. Assessment of the Building Components in the Energy Efficient Design of Tropical Residential Buildings: An Application of BIM and Statistical Taguchi Method. *Energy* **2019**, *188*, 116080. [CrossRef]
7. Schiavi, B.; Havard, V.; Beddiar, K.; Baudry, D. BIM Data Flow Architecture with AR/VR Technologies: Use Cases in Architecture, Engineering and Construction. *Autom. Constr.* **2022**, *134*, 104054. [CrossRef]
8. Amin Ranjbar, A.; Ansari, R.; Taherkhani, R.; Hosseini, M.R. Developing a Novel Cash Flow Risk Analysis Framework for Construction Projects Based on 5D BIM. *J. Build. Eng.* **2021**, *44*, 103341. [CrossRef]
9. Ildarabadi, P.; Alamatian, J. Proposing a New Function for Evaluation of the Financial Risk of Construction Projects Using Monte Carlo Method: Application on Iranian Construction Industry. *J. Build. Eng.* **2021**, *43*, 103143. [CrossRef]
10. Mashayekhi, A.; Heravi, G. A Decision-Making Framework Opted for Smart Building's Equipment Based on Energy Consumption and Cost Trade-off Using BIM and MIS. *J. Build. Eng.* **2020**, *32*, 101653. [CrossRef]
11. Alvanchi, A.; TohidiFar, A.; Mousavi, M.; Azad, R.; Rokooei, S. A Critical Study of the Existing Issues in Manufacturing Maintenance Systems: Can BIM Fill the Gap? *Comput. Ind.* **2021**, *131*, 103484. [CrossRef]
12. Tabatabaee, S.; Mahdiyar, A.; Durdyev, S.; Mohandes, S.R.; Ismail, S. An Assessment Model of Benefits, Opportunities, Costs, and Risks of Green Roof Installation: A Multi Criteria Decision Making Approach. *J. Clean. Prod.* **2019**, *238*, 117956. [CrossRef]
13. Davis, F.D. Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Q.* **1989**, *13*, 319–340. [CrossRef]
14. Alalwan, A.A.; Dwivedi, Y.K.; Rana, N.P. Factors Influencing Adoption of Mobile Banking by Jordanian Bank Customers: Extending UTAUT2 with Trust. *Int. J. Inf. Manag.* **2017**, *37*, 99–110. [CrossRef]
15. Mitropoulos, P.; Tatum, C.B. Technology Adoption Decisions in Construction Organizations. *J. Constr. Eng. Manag.* **1999**, *125*, 330–338. [CrossRef]
16. Sepasgozar, S.M.E. Digital Technology Utilisation Decisions for Facilitating the Implementation of Industry 4.0 Technologies. *Constr. Innov.* **2020**, *21*, 476–489. [CrossRef]
17. Arayici, Y.; Coates, P.; Koskela, L.; Kagioglou, M.; Usher, C.; O'Reilly, K. Technology Adoption in the BIM Implementation for Lean Architectural Practice. *Autom. Constr.* **2011**, *20*, 189–195. [CrossRef]
18. Chan, D.W.M.; Olawumi, T.O.; Ho, A.M.L. Perceived Benefits of and Barriers to Building Information Modelling (BIM) Implementation in Construction: The Case of Hong Kong. *J. Build. Eng.* **2019**, *25*, 100764. [CrossRef]
19. Lu, W.; Fung, A.; Peng, Y.; Liang, C.; Rowlinson, S. Cost-Benefit Analysis of Building Information Modeling Implementation in Building Projects through Demystification of Time-Effort Distribution Curves. *Build. Environ.* **2014**, *82*, 317–327. [CrossRef]
20. Seyis, S. Mixed Method Review for Integrating Building Information Modeling and Life-Cycle Assessments. *Build. Environ.* **2020**, *173*, 106703. [CrossRef]
21. Hong, Y.; Hammad, A.W.A.; Akbarnezhad, A.; Arashpour, M. A Neural Network Approach to Predicting the Net Costs Associated with BIM Adoption. *Autom. Constr.* **2020**, *119*, 103306. [CrossRef]
22. Mostafa, S.; Kim, K.P.; Tam, V.W.Y.; Rahnamayiezekavat, P. Exploring the Status, Benefits, Barriers and Opportunities of Using BIM for Advancing Prefabrication Practice. *Int. J. Constr. Manag.* **2020**, *20*, 146–156. [CrossRef]
23. Fernández-Alvarado, J.F.; Coloma-Miró, J.F.; Cortés-Pérez, J.P.; García-García, M.; Fernández-Rodríguez, S. Proposing a Sustainable Urban 3D Model to Minimize the Potential Risk Associated with Green Infrastructure by Applying Engineering Tools. *Sci. Total Environ.* **2021**, *812*, 152312. [CrossRef]
24. Röck, M.; Hollberg, A.; Habert, G.; Passer, A. LCA and BIM: Visualization of Environmental Potentials in Building Construction at Early Design Stages. *Build. Environ.* **2018**, *140*, 153–161. [CrossRef]
25. Hu, Z.; Zhang, J. BIM- and 4D-Based Integrated Solution of Analysis and Management for Conflicts and Structural Safety Problems during Construction. *Autom. Constr.* **2011**, *20*, 155–166. [CrossRef]
26. Opoku, A.; Deng, J.; Elmualim, A.; Ekung, S.; Hussien, A.A.; Abdalla, S.B. Sustainable Procurement in Construction and the Realisation of the Sustainable Development Goal (SDG) 12. *J. Clean. Prod.* **2022**, *376*, 134294. [CrossRef]
27. Alreshidi, E.; Mourshed, M.; Rezgui, Y. Factors for Effective BIM Governance. *J. Build. Eng.* **2017**, *10*, 89–101. [CrossRef]
28. Saieg, P.; Dominguez, E.; Nascimento, D.; Goyannes, R. Interactions of Building Information Modeling, Lean and Sustainability on the Architectural, Engineering and Construction Industry: A Systematic Review. *J. Clean. Prod.* **2018**, *174*, 788–806. [CrossRef]
29. Chien, K.-F.; Wu, Z.-H.; Huang, S.-C. Identifying and Assessing Critical Risk Factors for BIM Projects: Empirical Study. *Autom. Constr.* **2014**, *45*, 1–15. [CrossRef]
30. Olanrewaju, O.I.; Kineber, A.F.; Chileshe, N.; Edwards, D.J. Modelling the Relationship between Building Information Modelling (BIM) Implementation Barriers, Usage and Awareness on Building Project Lifecycle. *Build. Environ.* **2022**, *207*, 108556. [CrossRef]
31. Walasek, D.; Barszcz, A. Analysis of the Adoption Rate of Building Information Modeling [BIM] and Its Return on Investment [ROI]. *Procedia Eng.* **2017**, *172*, 1227–1234. [CrossRef]

32. Charef, R.; Emmitt, S.; Fouchal, F. Building Information Modelling Adoption in the European Union: An Overview. *J. Build. Eng.* **2019**, *25*, 100777. [CrossRef]
33. Eadie, R.; McLernon, T.; Patton, A. An Investigation into the Legal Issues Relating to Building Information Modelling (BIM). In Proceedings of the COBRA AUBEA 2015, Sydney, Australia, 8–10 July 2015.
34. Garcia, A.J.; Mollaoglu, S.; Syal, M. Implementation of BIM in Small Home-Building Businesses. *Am. Soc. Civil. Eng.* **2018**, *23*, 04018007. [CrossRef]
35. Ahmad, A.; Brahim, J. Roles and Responsibilities of Construction Players in Projects Using Building Information Modeling (BIM). *Prod. Lifecycle Manag. Era Internet Things* **2015**, *1*, 173–182. [CrossRef]
36. Ghaffarianhoseini, A.; Tookey, J.; Ghaffarianhoseini, A.; Naismith, N.; Azhar, S.; Efimova, O.; Raahemifar, K. Building Information Modelling (BIM) Uptake: Clear Benefits, Understanding Its Implementation, Risks and Challenges. *Renew. Sustain. Energy Rev.* **2017**, *75*, 1046–1053. [CrossRef]
37. Safari, K.; AzariJafari, H. Challenges and Opportunities for Integrating BIM and LCA: Methodological Choices and Framework Development. *Sustain. Cities Soc.* **2021**, *67*, 102728. [CrossRef]
38. Tan, T.; Chen, K.; Xue, F.; Lu, W. Barriers to Building Information Modeling (BIM) Implementation in China's Prefabricated Construction: An Interpretive Structural Modeling (ISM) Approach. *J. Clean. Prod.* **2019**, *219*, 949–959. [CrossRef]
39. Borges Viana, V.L.; Marques Carvalho, M.T. Prioritization of Risks Related to BIM Implementation in Brazilian Public Agencies Using Fuzzy Logic. *J. Build. Eng.* **2021**, *36*, 102104. [CrossRef]
40. Taghipour, A.; Rouyendegh, B.D.; Ünal, A.; Piya, S. Selection of Suppliers for Speech Recognition Products in IT Projects by Combining Techniques with an Integrated Fuzzy MCDM. *Sustainability* **2022**, *14*, 1777. [CrossRef]
41. Abowitz, D.A.; Toole, T.M. Mixed Method Research: Fundamental Issues of Design, Validity, and Reliability in Construction Research. *J. Constr. Eng. Manag.* **2010**, *136*, 108–116. [CrossRef]
42. Mohammadi, F.; Sadi, M.K.; Nateghi, F.; Abdullah, A.; Skitmore, M. A Hybrid Quality Function Deployment and Cybernetic Analytic Network Process Model for Project Manager Selection. *J. Civil. Eng. Manag.* **2014**, *20*, 795–809. [CrossRef]
43. Mohandes, S.R.; Sadeghi, H.; Mahdiyar, A.; Durdyev, S.; Banaitis, A.; Yahya, K.; Ismail, S. Assessing Construction Labours' Safety Level: A Fuzzy MCDM Approach. *J. Civil. Eng. Manag.* **2020**, *26*, 175–188. [CrossRef]
44. Bouzon, M.; Govindan, K.; Rodriguez, C.M.T.; Campos, L.M.S. Identification and Analysis of Reverse Logistics Barriers Using Fuzzy Delphi Method and AHP. *Resour. Conserv. Recycl.* **2016**, *108*, 182–197. [CrossRef]
45. Hallowell, M.R.; Gambatese, J.A. Qualitative Research: Application of the Delphi Method to CEM Research. *J. Constr. Eng. Manag.* **2010**, *136*, 99–107. [CrossRef]
46. Saaty, T.L.; Özdemir, M.S. How Many Judges Should There Be in a Group? *Ann. Data Sci.* **2015**, *1*, 359–368. [CrossRef]
47. Ebrahimi, S.; Bridgelall, R. A Fuzzy Delphi Analytic Hierarchy Model to Rank Factors Influencing Public Transit Mode Choice: A Case Study. *Res. Transp. Bus. Manag.* **2021**, *39*, 100496. [CrossRef]
48. Dalkey, N.; Helmer, O. An Experimental Application of the Delphi Method to the Use of Experts. *Manag. Sci* **1963**, *9*, 458–467. [CrossRef]
49. Shah, S.A.A.; Solangi, Y.A.; Ikram, M. Analysis of Barriers to the Adoption of Cleaner Energy Technologies in Pakistan Using Modified Delphi and Fuzzy Analytical Hierarchy Process. *J. Clean. Prod.* **2019**, *235*, 1037–1050. [CrossRef]
50. Gunduz, M.; Elsherbeny, H.A. Operational Framework for Managing Construction-Contract Administration Practitioners' Perspective through Modified Delphi Method. *J. Constr. Eng. Manag.* **2020**, *146*, 4019110. [CrossRef]
51. Hsu, Y.-L.; Lee, C.-H.; Kreng, V.B. The Application of Fuzzy Delphi Method and Fuzzy AHP in Lubricant Regenerative Technology Selection. *Expert Syst. Appl.* **2010**, *37*, 419–425. [CrossRef]
52. Mohandes, S.R.; Zhang, X. Towards the Development of a Comprehensive Hybrid Fuzzy-Based Occupational Risk Assessment Model for Construction Workers. *Saf. Sci.* **2019**, *115*, 294–309. [CrossRef]
53. Tabatabaee, S.; Ashour, M.; Mohandes, S.R.; Sadeghi, H.; Mahdiyar, A.; Hosseini, M.R.; Ismail, S. Deterrents to the Adoption of Green Walls: A Hybrid Fuzzy-Based Approach. *Eng. Constr. Archit. Manag.* **2022**, *29*, 3460–3479. [CrossRef]
54. Durdyev, S.; Mohandes, S.R.; Mahdiyar, A.; Ismail, S. What Drives Clients to Purchase Green Building?: The Cybernetic Fuzzy Analytic Hierarchy Process Approach. *Eng. Constr. Archit. Manag.* **2021**. ahead-of-print. [CrossRef]
55. Stanujkic, D.; Karabasevic, D.; Zavadskas, E.K.; Brauers, W.K.M. An Extension of the Multimoora Method for Solving Complex Decision-Making Problems Based on the Use of Interval-Valued Triangular Fuzzy Numbers. *Transform. Bus. Econ.* **2015**, *14*, 355–375.
56. Gurgun, A.P.; Koc, K. Contractor Prequalification for Green Buildings—Evidence from Turkey. *Eng. Constr. Archit. Manag.* **2020**, *27*, 1377–1400. [CrossRef]
57. Darko, A.; Chan, A.P.C.; Ameyaw, E.E.; Owusu, E.K.; Pärn, E.; Edwards, D.J. Review of Application of Analytic Hierarchy Process (AHP) in Construction. *Int. J. Constr. Manag.* **2018**, *19*, 436–452. [CrossRef]
58. Emrouznejad, A.; Marra, M. The State of the Art Development of AHP (1979–2017): A Literature Review with a Social Network Analysis. *Int. J. Prod. Res.* **2017**, *55*, 6653–6675. [CrossRef]
59. Abastante, F.; Corrente, S.; Greco, S.; Ishizaka, A.; Lami, I.M. A New Parsimonious AHP Methodology: Assigning Priorities to Many Objects by Comparing Pairwise Few Reference Objects. *Expert Syst. Appl.* **2019**, *127*, 109–120. [CrossRef]
60. Velasquez, M.; Hester, P.T. An Analysis of Multi-Criteria Decision Making Methods. *Int. J. Oper. Res.* **2013**, *10*, 56–66.

61. Dotoli, M.; Epicoco, N.; Falagario, M. Multi-Criteria Decision Making Techniques for the Management of Public Procurement Tenders: A Case Study. *Appl. Soft Comput.* **2020**, *88*, 106064. [CrossRef]
62. Chen, Z. A Cybernetic Model for Analytic Network Process. In Proceedings of the 2010 International Conference on Machine Learning and Cybernetics, Qingdao, China, 11–14 July 2010; Volume 4, pp. 1914–1919.
63. Leal, J.E. AHP-Express: A Simplified Version of the Analytical Hierarchy Process Method. *MethodsX* **2020**, *7*, 100748. [CrossRef]
64. Duleba, S. Introduction and Comparative Analysis of the Multi-Level Parsimonious AHP Methodology in a Public Transport Development Decision Problem. *J. Oper. Res. Soc.* **2020**, *73*, 230–243. [CrossRef]
65. Liu, Y.; Eckert, C.M.; Earl, C. A Review of Fuzzy AHP Methods for Decision-Making with Subjective Judgements. *Expert Syst. Appl.* **2020**, *161*, 113738. [CrossRef]
66. Mahdiyar, A.; Tabatabaee, S.; Durdyev, S.; Ismail, S.; Abdullah, A.; Wan Mohd Rani, W.N.M. A Prototype Decision Support System for Green Roof Type Selection: A Cybernetic Fuzzy ANP Method. *Sustain. Cities Soc.* **2019**, *48*, 101532. [CrossRef]
67. Ammarapala, V.; Chinda, T.; Pongsayaporn, P.; Ratanachot, W.; Punthutaecha, K.; Janmonta, K. Cross-Border Shipment Route Selection Utilizing Analytic Hierarchy Process (AHP) Method. *Songklanakarin J. Sci. Technol.* **2018**, *40*.
68. Alshorafa, R.; Ergen, E. Determining the level of development for BIM implementation in large-scale projects: A multi-case study. *Eng. Constr. Archit. Manag.* **2021**, *28*, 397–423. [CrossRef]
69. Karakhan, A.A.; Gambatese, J.A. Integrating Worker Health and Safety into Sustainable Design and Construction: Designer and Constructor Perspectives. *J. Constr. Eng. Manag.* **2017**, *143*, 31–37. [CrossRef]
70. Lucko, G.; Rojas, E.M. Research Validation: Challenges and Opportunities in the Construction Domain. *J. Constr. Eng. Manag.* **2010**, *136*, 127–135. [CrossRef]
71. Mahdiyar, A.; Mohandes, S.R.; Durdyev, S.; Tabatabaee, S.; Ismail, S. Barriers to Green Roof Installation: An Integrated Fuzzy-Based MCDM Approach. *J. Clean. Prod.* **2020**, *269*, 122365. [CrossRef]