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RESEARCH ARTICLE **Open Access**

An Integrated Approach for Evaluation Applications of Building Information Modeling based on Rough Number

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Abstract
Recently, Building Information Modeling (BIM) has emerged as a new technology in the construction industry, which is gradually gaining popularity among stakeholders. Despite the importance of BIM, the literature review shows a gap in the evaluation of BIM applications in Iran. Therefore, the aim of the current research is to evaluate the applications of BIM in construction projects. Since the evaluation of the most appropriate option is a multi-criteria decision-making problem. Therefore, decision makers use preferences that are uncertain in evaluating options. Rough's theory, which is efficient in such conditions, is used. First, by using the concept of Rough's theory to transform the preferences of experts and the combined method of Analysis Hierarchy Process (AHP) and VIKOR, is used for evaluation. The results show that the proposed decision method is effective improved objectivity in BIM application evaluation under subjective condition.
Keywords: *Building Information Modeling (BIM), Construction Projects, Analysis Hierarchy Process (AHP), VIKOR, Rough Set Theory*

Introduction

One of the primary responsibilities of a project management team in the construction industry is completing the project in terms of time, budget, and quality stated in the contract documents (Wang et al., 2004). Over time, the construction process becomes more complex, so controlling all aspects of the project requires an overview of its life cycle. Although the basic principles of success in achieving this goal are having an efficient and organized system of managing, monitoring, executing, collecting, and distributing project information among the different sections of the project, AutoCAD software designs have cast a shadow on this process (Bani Hashemi et al., 2011). Such shortcomings, especially in developing countries such as Iran, where low productivity, high levels of waste, high recurrent costs, and significant and chronic delays in the completion of building projects are constantly intensifying problems (Ghoddousi et al., 2015).The typical project management method used in most construction companies in Iran is a document-based approach, according to which the task of obtaining data from various departments involved in the construction phase is assigned to individuals. As a result, a wide range of

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construction data is routinely collected with a discrete nature regardless of their overall outcomes in the efficient management of the construction process. In recent years, Building Information Modeling (BIM) has emerged as a comprehensive concept of processes and tools that integrate and organize all data and information required by projects. It supports new workflows and integrates them more accurately through existing simulation and analysis tools used by consultants and contractors (Eastman et al., 2011). Since most processes in BIM are automated and human resource participation is minimal, it is claimed that through the use of BIM, the effectiveness of monitoring, control, and management in the life cycle of building projects is increased significantly (Golparvar-Fard., 2015). However, despite the approved benefits of using BIM in building projects and the trend observed in its global application, its implementation rate is much lower than its current potential in Iran, especially in the construction phase (Hosseini et al.,2016). The root cause of this may be the lack of relevant studies and research in the literature on the application of BIM in the construction phase of building projects in Iran and its contribution to project management Key Performance Indicators (KPIs). There is an evident lack of studies to identify potential application areas of BIM and its relationship to KPIs in the construction industry. Against this background, evaluating decision criteria for those building dimensions of BIM and their relative importance concerning KPIs such as time, cost, and quality can be important for project implementers and policymakers. However, appropriate decision-making criteria based on BIM and KPIs should include the tradeoff and situational and complex evaluation of the various processes that require simultaneous evaluation and prioritization of all options. The VIKOR method was developed by Opericovic (1988) and Opericovic and Tzeng (2002) as a multi-criteria optimization method for complex systems. Here the compromise solution is the closest justified solution to the ideal solution, where the word compromise refers to a mutual agreement, and finally, the prioritization of options is presented. However, VIKOR is not a standalone method because it cannot calculate the criteria weights. Accordingly, it is better first to calculate the criteria weights using the Analytical Hierarchy Process (AHP), which is one of the most well-known and widely used multi-criteria decision-making methods, and then feed it as input to the VIKOR method. L. Saati proposed AHP in 1988. It has been applied in various studies such as risk identification and assessment (Lyu et al., 2020), sustainability assessment (Bani Hashemi et al., 2019), identify and analyze of the dimensions of innovation capability (Bahrami et al., 2022), identification and prioritization of measures to reduce the failure of safety policies (shahsavari goqeri et al., 2022), designing a native model for assessment of the effectiveness of advertising (Shamsadini et al., 2019), identify dynamic capabilities of knowledge management and knowledge management process capabilities (Dehghani, 2016), identifying and ranking technology-telecommunications context of information security management system in e-government (Javid & Yaghoubi, 2016), and key performance indicators (Ugwu & Haupt, 2007). However, the inability of the hybrid method to minimize the subjectivity and the inherent uncertainty in quantifying an expert's judgment in the form of an exact number makes it necessary to combine its method with more advanced methods. Therefore, using the rough technique within the AHP and VIKOR structures seems to be a promising approach to meet this challenge (Sabet Motlagh, 2018). A review of the literature shows that no research has examined the capabilities of BIM in the construction phase of building projects in Iran, and the link with KPIs through a robust approach has not been established. The various capabilities of BIM in performance development and productivity have been explicitly acknowledged and confirmed in major construction-related studies (Azhar, 2011; Sun et al., 2015). Hence, there is a growing tendency to adopt and implement BIM globally throughout the construction industry. This trend encompasses a wide range of countries in the Middle East that have sought to improve BIM implementation in their building projects (Hosseini et al., 2015). Although evidence-based documents prove that Iran lags in adopting the BIM method in construction projects, no research has provided an overview of the potential application of BIM in the country. Current studies in the Middle East, such as the Building Smart Survey (2011), are biased toward the Persian Gulf countries and have not covered all Middle Eastern countries (e.g., Iran, Israel, and Turkey) (Wang et al., 2004). Other BIM-related studies in developing countries have focused on countries other than Iran, such as Malaysia, Sri Lanka (Rogers et al, 2011), and India (Kumar and Mukherjee, 2009). Determinants of applications and actions related to BIM are formed through the context of the industry and, thus, should be considered within the natural context of a country or company (Aranda-Mena et al., 2008; Poirier et al., 2015). Also, the findings of studies from other countries cannot be used directly in the Iranian context and structure. In addition, published and available studies on BIM in Iran, such as the study by Kiani et al. (2015), focus solely on applying BIM to project scheduling and planning. We can also refer to the study by Khanzadi et al. (2018) that only assesses BIM from a managerial point of view to provide insight into the application of BIM in building projects in Iran; hence, the status of BIM in Iran remains unknown (Wang et al., 2004). This research seeks to address these issues. The first goal is to discover KPIs in the construction field within the Iranian context. Then, the potential dimensions of BIM application in the construction phase of building projects are identified from the perspective of Iranian experts and specialists. Finally, the prioritization of BIM applications by applying the concept of rough set theory in a hybrid approach is proposed.

2. Literature Review

The current trend of economic growth in Iran has led to increased demand for construction projects, praising the efforts made for the proper management of these projects. As a result, project managers in Iran still fail to accept and understand the concept of productivity and success in project management (Ghoddousi et al., 2015). In 2016, Iran's GDP was estimated at $412.2 billion, making it the second-largest economy in the Middle East and North Africa after Saudi Arabia. Of this amount, the construction market in Iran accounted for a significant figure of $154 billion (Ghoddousi et al., 2015; Khanzadi et al., 2018) and is expected to increase to $196 billion by 2020. The lifting of recent sanctions and the consequent injection of foreign direct investment will help accelerate Iran's plans to develop infrastructure. The size of the country's construction projects has doubled, and many mega projects have been announced to develop dams, tunnels, and industrial assets. In principle, construction project managers in the global and local context are expected to present projects in the form of managerial goals. However, the low productivity and fragmentation of the Iranian construction industry require a severe paradigm shift in terms of construction KPIs considering emerging methods and technologies. Previous studies have identified key indicators for integration with construction project management practices to address this type of challenge. The literature shows that knowledge of these indicators plays a more critical role in integrating them with project management operations than social and cultural stimuli (Zhang et al., 2014)

In this regard, by reviewing the primary studies, it was found that time, cost, and quality are the main pillars of performance indicators in construction (Chan & Chan, 2004). As mentioned before, BIM, due to its superior ability to coordinate and organize the process of construction projects, can play an essential and vital role by benefiting from construction KPIs (Wang et al., 2004; Khanzadi et al., 2018). Therefore, in line with the aims of this research, the applications of BIM according to the KPIs of construction projects were explored through a comprehensive review of the literature focusing on the construction phase of the life cycle of construction projects. This resulted in a list of 15 dimensions that are presented in the Table 1.

Table 1
Dimensions of Building Information Modeling (BIM) in the construction phase (Khanzadi et al., 2019)

Applications of Building Information Modeling (BIM)
Safety
Preparation
Project Coordination
Ability to Build
Recognizing Conflict and Conflict
Project Supply Chain
Site layout planning
Project Schedule and Construction Sequence
Estimation and Cost Estimation
Construction Supervision
Integration of Subcontractor and Supplier Data
Flexible Project Changes
Optimization of Project Logistics
Automated Compatibility and Compliance Checks
Reduction of Rework

BIM involves the collection, use, and digital presentation of all building information for different phases of the project life cycle in the form of a repository or data source. It also provides a comprehensive concept as an umbrella for processes and tools that provides all the data needed by projects by combining the information needed in specific phases and stages of the building life cycle (scheduling, analysis, cost assessment, and the like) (Khanzadi et al., 2018).

BIM, however, is more than just a data container for a building model. It is a specific model of object-oriented building construction and design to help advance the exchange and interaction of data digitally. The main advantage of using BIM in the design and construction phase of a project is its ability to model and test the ability to build a design within the model before entering the project site. Also, as a management paradigm, it can be implemented through information and communication technology chains, including editing and design tools such as Revit, ArchiCAD, Microstation, and Navisworks (Bani Hashemi et al., 2011).

Implementing BIM helps to avoid errors and improve the productivity, timing, safety, cost, and quality of construction projects. It is a fast and effective process by which information about a project can be updated at any stage and through any unit or department (such as an engineering unit) (Hosseini et al., 2015). Accordingly, due to the efficiency of BIM in adopting and publishing model changes, editing objects, and reloading updated links, the entire project model will be updated based on changes in one aspect of the project. It is claimed that BIM can overcome the problems caused by the discrete structure of the industry while increasing performance within the industry and assists in the radical restructuring of the construction industry as a catalyst for change from two-dimensional to three-dimensional modeling and a new change in four-dimensional form (in combination with the project scheduling factor), five-dimensional (in conjunction with the project cost factor), and six-dimensional (in conjunction with the facility management factor), using the smart data analysis techniques to achieve the best BIM performance using as/built plans.

The value of BIM in developing countries is not fully recognized as a dynamic research area, and there are few studies in this field. Research conducted by Building Smart (2016) in several Middle Eastern countries showed that despite the interest and optimism in BIM, the construction industry is still in the early stages of adoption (Wang et al., 2004). According to Building Smart (2012), the findings generally indicate an optimistic and knowledgeable market but inexperienced in BIM. Therefore, the literature review findings confirm and reaffirm the discussions related to the need for exploratory research on BIM in Iran (Wang et al., 2004; Aboushady & Elbarkouky., 2015). Thus, the present study attempts to apply the BIM concept in line with the KPIs of construction projects in Iran and to discover the KPIs of the construction industry by applying the rough sets theory in the Iranian text. Then, the potential dimensions of BIM application in the construction phase of construction projects are identified from the perspective of Iranian experts and specialists. Finally, we examine the links between KPIs in the field of construction and BIM competency criteria and their relative importance by applying the concept of rough sets theory using a hybrid approach. The general algorithm of the research structure is presented in Fig. 1:

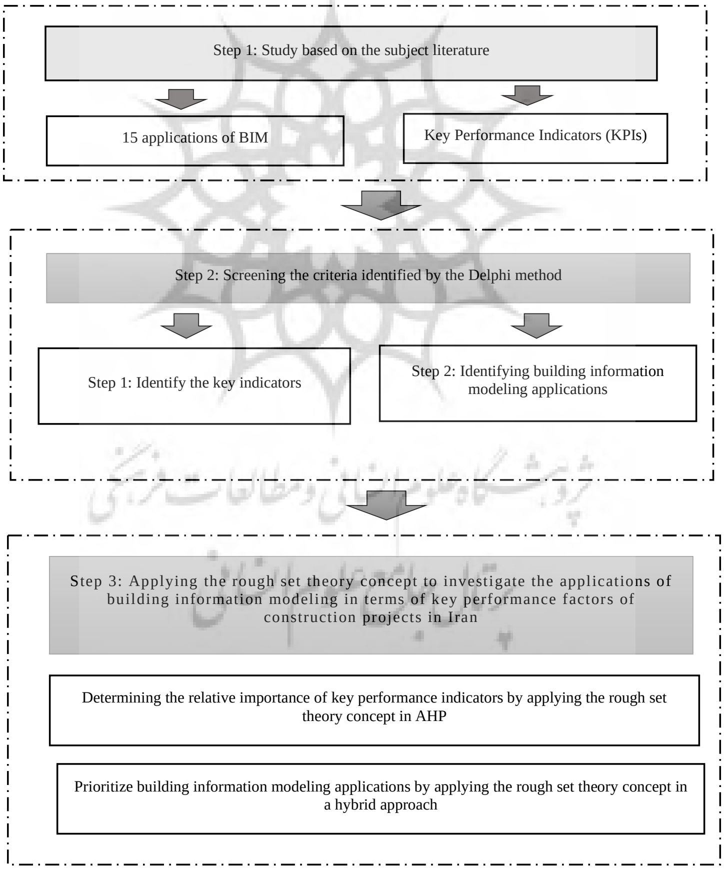

Fig. (1). *Research Execution Algorithm*

3. Research Methodology

The primary goal of this study is to apply the rough set theory concept to investigate the applications of BIM in line with the KPIs of construction projects in Iran. A hybrid research method will be used to achieve this goal because this method is one of the most practical research methods in management, which is obtained by combining qualitative and quantitative methods. In the first step, the present study identified the key performance indicators and applications of building information modeling by examining the research literature and experts' opinions. Then, after identifying the KPIs and applications of BIM, a hierarchical structure was formed. In the next step, using the Delphi method, the KPIs and applications of BIM were evaluated. After confirming the research criteria, a Pairwise Comparison Matrix (PCM) of criteria was formed. The CPM of experts was transformed into interval numbers using the rough set theory concept; then, the weight of the criteria was obtained using the rough AHP. After determining the weight of the criteria, the decision matrix of the problem was formed, the decision matrix data was converted into interval numbers using the rough set theory concept, and then the BIM applications were evaluated and ranked using the VIKOR-Rough method. Accordingly, before presenting the research results, the necessary concepts and relationships required about the rough set theory and the rough decision-making methods used in this research are presented to help better understand the presented results.

3.1. Qualitative Stage

This stage covered the customization of the key criteria of construction project management and the initial list of BIM performance dimensions in the construction stage (taken from the subject literature) within the text and structure of Iran. The key performance criteria in the field of construction are highly text-oriented and should be adopted according to the text and related structure. In addition, the technical benefits of BIM should be examined from the perspective of local and technological competencies. Therefore, the Delphi method was chosen for this purpose, which is an organized procedure to achieve consensus and agreement among an expert panel through frequent discussions in the form of interviews or questionnaires. In general, the number of relevant meetings varies from two to seven and the number of participants varies from three to fifteen people. With the launch of each round of the meeting, the answers are analyzed and based on the evaluation, interviews or semi-structured questionnaires are prepared and sent to the experts of the next meeting. The repetitive nature of this method provides feedback from the panel and new information from different perspectives. This opportunity allows them to review their ideas in the previous meeting and revise and modify them based on new suggestions.

3.2. Quantitative Stage

This stage includes quantifying the level of importance of key performance indicators in the field of construction through the AHP method and the benefits of BIM in the construction phase of construction projects. In general, measuring building information modeling capabilities includes two parts: 1) determining the relative importance of the evaluation index; 2) Ranking decision-making options. Since we are usually faced with insufficient and incomplete information in the real world, therefore, due to the lack of proper and complete information and data in the real world, we must use methods that have the ability to work in such environments. One of the concepts used in such environments is rough theory, which can work well in the absence of sufficient and complete information. In this regard, the present study proposes an integrated approach by introducing rough numbers to the AHP-VIKOR technique in order to eliminate ambiguity in the decision-making process. In the first step, to calculate the relative importance of the evaluation indices, rough numbers are combined with AHP and the results are obtained. Then the research presents a rough VIKOR to measure decision-making options. By combining rough AHP and rough VIKOR, both the relative importance of evaluation indicators and the ranking of decision options are determined without any auxiliary information. Therefore, the proposed method can effectively reflect the real perception of decision-makers and strengthen the objectivity of the design concept evaluation (Sabet Motlagh., 2018)

In the following, before presenting the results of the research, the necessary concepts and relationships about the Raff set theory and the Raff decision-making methods used in this research have been presented in order to help in a better understanding of the presented results.

3.2.1. Rough Set Theory

Introduced by Pawlak in 1982, rough sets are valuable mathematical tools in ambiguous and uncertain conditions. Rough is an artificial intelligence approach that constitutes cognitive science, machine learning, knowledge acquisition, decision analysis, knowledge discovery, decision support systems, inferential reasoning, and pattern recognition. Zhai, Xu, and Zhong (2008) proposed the rough numbers some 26 years after the theory's introduction. A rough number usually constitutes the lower and upper bounds and the rough border distance, which depends only on the original data. Therefore, there is no need for auxiliary information, and the method can easily understand the concepts considered by experts and improve decision-making objectivity (Pawlak, 1982). Suppose U is a reference set consisting of all members; Y is an arbitrary member of the set U; and R is a set of t classes ($R = \{G_1,\ldots, G_t\}$) that covers all members of U. If these classes are sequentially the same as $G_1<G_2<\ldots<G_t$, then $1\leq q\leq t$, $\forall y \in U, G_q$. The lower approximation ($\underline{Apr}$ (G_q))), the upper approximation ($\overline{Apr}$ (Gq)) and the boundary region (Bnd (G_q)) of the G_q class are defined as follows:

$$\underline{Apr}\,(G_q) = \cup\{(Y\epsilon U|R(Y) \leq G_q)\} \tag{1}$$

$$\overline{Apr}(G_q) = \cup\{(Y\epsilon U|R(Y) \geq G_q)\} \tag{2}$$

$$\text{Bnd}(G_q)=\cup\{(Y\epsilon U|R(Y) \neq G_q)\} = \{(Y\epsilon U|R(Y) > G_q)\} \cup\{(Y\epsilon U|R(Y) \cdot \tag{3}$$

G_q can then be represented by a rough number $RN(G_q)$ at its corresponding lower and upper bounds (Eqs. (1) to (3)).

$$\underline{Lim}\,(G_q)=\frac{1}{M_L}\sum R(y)|Y\epsilon \underline{Apr}\,(G_q) \tag{4}$$

$$\overline{Lim}\,(G_q)=\frac{1}{M_U}\sum R(y)|Y\epsilon\, \overline{Apr}(G_q) \tag{5}$$

$$\text{RN}\,(G_q)= [\underline{Lim}\,(Gq), \overline{Lim}\,(Gq)] \tag{6}$$

where M_L and M_U are the values of members (G_q) $\underline{Apr}$ and (G_q) $\overline{Apr}$, respectively. It is clear that the lower and upper bounds determine the mean value of the elements concerning the high and low approximations, respectively, and their difference is defined by the rough boundary distance (Pawlak, 1987).

$$\text{IRBnd}\,(G_q)= \overline{Lim}\,(Gq) - \underline{Lim}\,(Gq) \tag{7}$$

The rough boundary distance expresses the ambiguity of G_q, so that the larger the number, the greater the ambiguity, while the smaller the number, the more accurate it is. Therefore, mental information can be expressed in rough numbers. Since the generated rough numbers are similar to spaced numbers, the computational rules of interval numbers can also be used in rough numbers.

3.2.2. Rough Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is one of the most well-known and widely used multi-criteria decision-making methods to measure the degree of consistency of preferences and consider tangible and intangible criteria. In this study, the rough AHP has been used due to the subjectivity and ambiguity of the experts' judgments. The rough AHP steps are as follows (Zhou et al., 2015):

- Step 1: Identify the purpose, criteria, and research options and form a hierarchical structure.
- Step 2: Prepare a pairwise comparison questionnaire and collect expert opinions.
- Step 3: Use the rough sets theory concept to convert expert preferences to interval numbers and form a pairwise comparison matrix (PCM) such as Eq. (8):

$$\begin{bmatrix} [1,1] & [x_{12}^L, x_{12}^U] & \dots & [x_{1m}^L, x_{1n}^U] \\ [x_{21}^L, x_{21}^U] & [1,1] & \dots & [x_{2m}^L, x_{2n}^U] \\ \vdots & \vdots & & \vdots \\ [x_{m1}^L, x_{m1}^U] & \dots & & [1,1] \end{bmatrix} \quad (8)$$

In this equation, x_{ij}^L is the lower limit and x_{ij}^U is the upper limit of the interval numbers.
Before calculating the interval numbers, the incompatibility rate of the pairwise comparison questionnaires should be calculated, and if their incompatibility rate was acceptable (< 0.1), the interval numbers should be calculated.
Step 4: Calculate the weight of each of the research criteria using Eqs. (9) and (10):

$$w_i = \left[\sqrt[m]{\prod_{j=1}^{m} x_{ij}^L}, \sqrt[m]{\prod_{j=1}^{m} x_{ij}^U}\right] \quad (9)$$

$$\acute{w}_i = {w_i}/{\max(w_i^u)} \quad (10)$$

In Eq. (7), $\acute{w}_i$ is the normalized form, which ultimately achieves the weight of the research criteria (Zhou et al., 2015).

3.2.3. Rough VIKOR method

VIKOR's method was developed by Opricovic (1988) and Opricovic & Tzeng (2002) for multi-criteria optimization of complex systems. Here the compromise solution is the closest justified solution to the ideal answer, where the word compromise refers to a mutual agreement (Opricovic & Tzeng, 2004). The assumptions and steps of the proposed method are as follows (Chu et al., 2007):

Hypothesis:

- There are *k* decision-makers who have equally important opinions in the final decision *(k = 1, 2, …, k)*.
- There are *m* options *(i = 1, 2, …, m)*.
- There are *n* criteria/factors for decision making *(j = 1, 2, …, n)*.

Step 1: Form the decision distance matrix obtained from the rough set theory.

$$D = \begin{bmatrix} [f_{11}^L, f_{11}^U] & [f_{12}^L, f_{12}^U] & \dots & [f_{1m}^L, f_{1m}^U] \\ [f_{21}^L, f_{21}^U] & [f_{22}^L, f_{22}^U] & \dots & [f_{2m}^L, f_{2m}^U] \\ \vdots & \vdots & \vdots & \vdots \\ [f_{n1}^L, f_{n1}^U] & [f_{n2}^L, f_{n2}^U] & \dots & [f_{nm}^L, f_{nm}^U] \end{bmatrix} \quad (11)$$

Step 2: Identify the best f_j^* value and the worst value f_j^- in each criterion of the matrix D. For a positive criterion (with a profit nature), the most significant number indicates the best value, and the smallest number represents the worst value:

$$f_j^* = Max_i f_{ij}^U, f_{ij}^- = Min_i f_{ij}^L \quad (12)$$

For a negative criterion (with a cost nature), the opposite is true:

$$f_j^* = Min_i f_{ij}^L, f_{ij}^- = Max_i f_{ij}^U \quad (13)$$

In general, the best and worst values are obtained as follows.

$$f_j^* = \{(Max_i f_{ij}^U | j\epsilon B) or (Min_i f_{ij}^L | j\epsilon C)\} \quad (14)$$

$$f_j^- = \{(Min_i f_{ij}^L | j\epsilon B) or (Max_i f_{ij}^U | j\epsilon C)\} \quad (15)$$

where B is a set of positive criteria and C is a set of negative criteria.
Step 3: Calculate the values of $[s_i^L, s_i^U]$ and $[R_i^L, R_i^U]$.

$$s_i^L = \sum_{j\epsilon B} w_j^l \left(\frac{f_j^* - f_{ij}^U}{f_j^* - f_{ij}^-}\right) + \sum_{j\epsilon C} w_j^l \left(\frac{f_{ij}^L - f_j^*}{f_j^- - f_j^*}\right) \quad (16)$$

$$s_i^U = \sum_{j\epsilon B} w_j^U \left(\frac{f_j^* - f_{ij}^L}{f_j^* - f_j^-}\right) + \sum_{j\epsilon C} w_j^U \left(\frac{f_{ij}^L - f_j^*}{f_j^- - f_j^*}\right) \quad (17)$$

$$R_i^L = max_j = \begin{cases} w_j^l \left(\frac{f_j^* - f_{ij}^U}{f_j^* - f_{ij}^-}\right) | j\epsilon B \\ w_j^l \left(\frac{f_{ij}^L - f_j^*}{f_j^- - f_j^*}\right) | j\epsilon C \end{cases} \quad (18)$$

$$R_i^U = max_j = \begin{cases} w_j^U \left(\frac{f_j^* - f_{ij}^L}{f_j^* - f_{ij}^-}\right) | j\epsilon B \\ w_j^U \left(\frac{f_{ij}^U - f_j^*}{f_j^- - f_j^*}\right) | j\epsilon C \end{cases} \quad (19)$$

where w_j^L is the lower limit and w_j^U is the upper limit of the standard weight.
Step 4: Calculate the values $[Q_i^L, Q_i^U]$

$$Q_i^L = v\left(\frac{S_i^L - S^*}{S^- - S^*}\right) + (1 - v)\left(\frac{R_i^L - R^*}{R^- - R^*}\right) \quad (20)$$

$$Q_i^U = v\left(\frac{S_i^U - S^*}{S^- - S^*}\right) + (1 - v)\left(\frac{R_i^U - R^*}{R^- - R^*}\right) \quad (21)$$

$S^* = Min_i S_i^L$, $S^- = Max_i S_i^U$, $R^* = Min_i R_i^L$, $R^* = Max_i R_i^U$, and Q is a cumulative index.

Also, *v* represents the weight of the maximum criteria and is v = 0.5, usually vϵ [0,1].
Step 5: Rank the options based on S, R, and Q.

4. Case Study and Experimental Findings

In the present study, we attempt to study the applications of BIM in line with the KPIs of construction projects in Iran by applying the rough set theory concept. For this purpose, all the steps presented in Fig. (1) were implemented in the study. The study's statistical population was the specialists and experts of companies operating in BIM applications in Iran. Ten companies were selected as the research sample to complete the pairwise comparison questionnaire and VIKOR questionnaire among the participating companies. As shown in Fig. (1), the first step in this study is to identify KPIs and BIM applications using the research literature and expert opinion. Then, after identifying the KPIs and BIM applications, a hierarchical structure is formed, and in the next step, the KPIs and BIM applications are evaluated using the Delphi method. Figure 2 shows the hierarchical structure of KPIs and BIM applications.

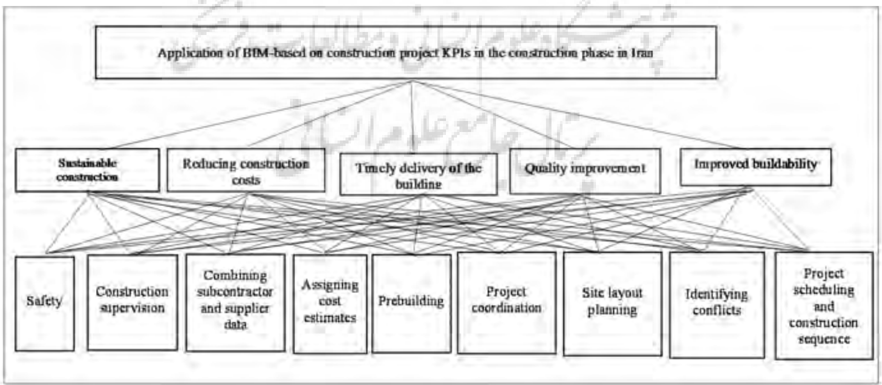

Fig. (2). *Hierarchical structure of research*

After confirming the research criteria, the criteria pairwise comparison matrix (PCM) is formed, and the experts' CPM is converted into interval numbers using the rough set theory concept. Then, the weight of the criteria is obtained using AHP. The experts' CPM results and the final weight are presented in Tables 2 and 3.

Table 2

Cumulative expert opinion results in the pairwise comparison matrices

	C1	C2	C3	C4	C5
C1	[1,1]	[1.286,3.173]	[1.62,3.488]	[1.979, 3.26]	[2.346, 4.93]
C2	[0.315, 0.777]	[1,1]	[3.015,4.421]	[1.295,3.131]	[١,٦١٦،٣,٠٩١]
C3	[0.287, 0.617]	[0.226,0.332]	[1,1]	[1.242,2.174]	[٢,٨٢٧،٤,٧١]
C4	[٠,٣٠٦،٠,٥٠٥]	[٠,٣١٩،٠,٧٩٤]	[٠,٤٦،٠,٨٠٥]	[١،١]	[٢,٨٥،٥,٦٧٩]
C5	[٠,٢٠٣،٠,٤٢٦]	[٠,٣٢٤،٠,٦١٩]	[٠,٢١٢،٠,٣٥٤]	[٠,١٧٦،٠,٣٥١]	[١،١]

Table 3

Results of calculating the criteria weights

	Rough weight	Crisp weight	Normal weight	rank
C1	[٠,٥٥٨،١]	. 779	. 365	١
C2	[٠,٤٠٥،٠,٧١٥]	. 560	. 262	٢
C3	[٠,٢٦٤،٠,٤١١]	. 338	. 158	٣
C4	[٠,٢٣٥،٠,٤٠١]	. 318	. 149	٤
C5	[٠,١٠٧،٠,١٧٩]	. 142	. 067	٥

After calculating the research criteria weights, the next step is to form a problem decision matrix. To form the interval decision matrix, expert opinions on each of the options in each of the criteria were collected using the VIKOR questionnaire, the results of which are presented in Table 4.

Table 4

The interval decision matrix obtained from the rough set theory

	C1	C2	C3	C4	C5
A1	[٢,١٥،٢,٨٧٥]	[٦،٦]	[٥,٤١٣،٦,١٦٩]	[٤,٦٢،٤,٩٨]	[١,٢٢٤،٢,١٩٥]
A2	[٦,٦٢،٦,٩٨]	[٥,٠٥،٥,٩٢٨]	[٦,٨٦،٧,٩٤]	[٢,٠١،٢,١٩]	[١,١١٣،١,٩١٧]
A3	[٧,٦٢،٧,٩٨]	[٤,٩٦،٧,٠٥١]	[٢،٢]	[٤,٢٨،٤,٩٢]	[٧,٦٧،٨,٩٣]
A4	[٨،٨]	[٢,٠٢،٢,٣٨]	[٩،٩]	[٣,٤١،٣,٩٥٩]	[٧,٨١،٧,٩٩]
A5	[٢،٢]	[٦،٦]	[٤,٨١،٤,٩٩]	[٣،٣]	[٢,٠١،٢,١٩]
A6	[٣,٠١،٣,١٩]	[١,١٧،٢,٠٦]	[١,٣٦٧،٢,٧٦٧]	[٨،٨]	[٦،٦]
A7	[٥,٤١،٥,٩٥٩]	[٤,٦٢،٤,٩٨]	[٥,٤٣،٥,٩٧]	[٦,٢٤،٦,٩٦]	[٥,٤٣،٥,٩٧]
A8	[٣,٩٨،٤,٨٢]	[٤,٠١،٤,١٩]	[٦،٦]	[٥،٥]	[٧،٧]
A9	[٦،٦]	[٧,٢٤،٧,٩٦]	[٧،٧]	[٣,٠١،٣,١٩]	[٢,٠٩،٢,٥١]

We evaluate research options by creating a problem decision table using the VIKOR-Rough equations. After forming the decision matrix, the first step in the VIKOR-Rough method is determining the positive ideal and negative ideal values in each of the decision matrix criteria. Accordingly, if the criterion has a positive aspect, the positive ideal is equal to the largest upper limit, and the negative ideal is equal to the smallest lower limit of each column of the criterion of the decision matrix, and vice versa for the negative criteria. In the present study, all criteria have a positive aspect. Table 5 shows the obtained results.

Table 5

Positive and negative ideals

	C1	C2	C3	C4	C5
f*	[٨،٨]	[٧,٩٦،٧,٩٦]	[٩،٩]	[٨،٨]	[٨,٩٣،٨,٩٣]
f-	[٢،٢]	[١,١٧،١,١٧]	[١,٣٦٧،١,٣٦٧]	[٢,٠١،٢,٠١]	[١,١١٣،١,١١٣]

The next step is to use the equations (16-19) to calculate the indicators of usefulness and regret. Once these indicators are specified, the leading VIKOR indicator, i.e., the Q- indicator for each option, is calculated. For this purpose, equations (20) and (21) have been used. The results of these calculations are given in Table 6.

Table 6

Indicators obtained from the VIKOR-Rough method

	S	**S Crisp**	**R**	**R Crisp**	**Q**	**Q Crisp**	**رتبه**
A1	[٠,٩٠٢،١,٧٧٧]	١,٣٤٠	[٠,٤٧٧،٠,٩٧٥]	٠,٧٢٦	[٠,٣٢٨،٠,٩٠٧]	٠,٦١٨	٧
A2	[٠,٥٧٧،١,٢٣١]	٠,٩٠٤	[٠,٢٢٨،٠,٤٠١]	٠,٣١٤	[٠,٠٧٣،٠,٣٨٣]	٠,٢٢٨	٤
A3	[٠,٤١٩،١,٠٣٤]	٠,٧٢٦	[٠,٢٤٢،٠,٣٧٧]	٠,٣١٠	[٠,٠٣٣،٠,٣٠٨]	٠,١٧٠	٢
A4	[٠,٥٠٤،٠,٩٥٨]	٠,٧٣١	[٠,٣٣٣،٠,٦٢٥]	٠,٤٧٩	[٠,١١٥،٠,٤٣٧]	٠,٢٧٦	٥
A5	[١,١٠٢،١,٩٢٥]	١,٥١٤	[٠,٥٥٨،١]	٠,٧٧٩	[٠,٤٤١،٠,٩٦٩]	٠,٧٠٥	٩
A6	[١,٠٥٥،٢,٠٢٥]	١,٥٤٠	[٠,٤٤٨،٠,٨٣٢]	٠,٦٤٠	[٠,٣٥٧،٠,٨٩٦]	٠,٦٢٧	٨
A7	[٠,٥٥٤،١,١٧٤]	٠,٨٦٤	[٠,١٩،٠,٤٣٢]	٠,٣١١	[٠,٠٤٣،٠,٣٨٥]	٠,٢١٤	٣
A8	[٠,٧٦٩،١,٤٩٢]	١,١٣٠	[٠,٢٩٦،٠,٦٧]	٠,٤٨٣	[٠,١٧٥،٠,٦٣١]	٠,٤٠٣	٦
A9	[٠,٥٣٢،١,٠٠٧]	٠,٧٦٩	[٠,١٨٩،٠,٣٣٤]	٠,٢٦١	[٠,٠٣٥،٠,٢٧٢]	٠,١٥٤	١

According to the VIKOR conditions, option A9 has the lowest Q-value. On the other hand, in order for the top-ranked option to be identified, the following relation should be checked: relation $Q(A3) - Q(A9) \geq \frac{1}{9-1} \Rrightarrow 0.17 - 0.154 < 0.125$ is not established, so options A3 and A9 are selected as the top options. Therefore, both project coordination options (A3) and project time planning and construction sequence (A9) are selected as the best option. Then, in the order of conflict detection and collision (A7), integration of sub-contractor and supplier data (A2), safety (A5), cost estimation and estimation (A8), site layout planning (A1), pre-construction (A6) and construction supervision (A5) are other ranking options by VIKOR method. The overall findings of the importance of evaluation indicators, according to the relative importance of each key performance indicator compared to others, show that quality improvement has received the highest level of attention among all indicators. The descending order of other classes according to the level of importance is as follows: reduction of construction cost, sustainable construction, improvement of construction capability and delivery of the building in terms of time efficiency. This result is confirmed with a weight of 0.365 for the quality improvement class, which is much higher and more important than other indicators that are evaluated according to BIM technology and the construction stage of the project life cycle. It has been confirmed that BIM has a significant capacity and potential to improve the construction quality management process by changing the way project participants interact with each other and maintaining information in an integrated database.

The next important indicator is the reduction of construction costs. The reduction of construction cost is mainly known as a key asset in the financial turnover of the construction industry and it seems that the importance of this indicator is more in the context of Iran because the Iranian construction industry has a low profitability rate and high failure rate due to Irregularity of customer payments. This problem is aggravated due to the recent recession and national economic crisis, which is caused by the widespread recession resulting from international sanctions. It is obvious that the first relevant application of BIM for this indicator is the estimation and cost estimation, which can be done through the driving force of the powerful five-dimensional modeling of building information, meters and automatic estimation. Five-dimensional modeling of building information projects the exact form of output values of the required quantities using a specialized measurement tool and strong solutions to maintain homogeneity of cost data. The next key performance indicator that helps to improve the usability of BIM in the construction industry is the sustainable construction key indicator. BIM promotes the key performance indicators of sustainable construction at the design stage, especially where advanced techniques such as energy efficient development can be developed and incorporated. The technological aspect of BIM helps the team involved in each project to observe and examine what will be built in a simulated environment and to identify possible problems in the construction design and operation in advance. The process-oriented aspect of BIM enables and encourages the close cooperation of different involved groups and makes the flow of information between them simple and possible. The key indicator of the next performance, namely "buildability", is defined as "the plan of efforts that can be used in the construction phase and allows the contractors to carry out the activities easily and smoothly". Based on this definition, the designer must have an understanding of construction, but due to the lack of communication and coordination in the local context, the designer usually lacks this feature. In the end, the building delivery index has a lower degree of importance than others in terms of time efficiency. It is obvious that BIM four-dimensional simulation technique; The integration of project scheduling and planning with the 3D model reduces the construction project delivery time through the automatic identification of delays and collaborative space between the contractor and subcontractors. This technique visualizes and visualizes the structure of the work breakdown of the construction process in the planning and scheduling of all components of the 3D model.

5. Analysis of Experimental Findings

As mentioned earlier, the present study aims to apply the rough set theory concept to investigate the applications of building information modeling in line with key performance indicators of construction projects in Iran and as a basis for filling the knowledge gap (i.e., lack of studies in application-based BIM to guide and control the KPIs in the construction cycle of the project life cycle in Iran) is presented. This research was the first research of its kind, based on the literature related to the KPIs and dimensions of BIM in the construction industry. Using the initial Delphi method, the relevant areas were determined per the conditions of Iran, and after reviewing and screening the criteria, the hierarchical structure of the research was determined. In the next step, by applying the rough set theory concept in multi-criteria decision-making methods, the applications of BIM in terms of KPIs of construction projects in Iran were explored. The findings of this study showed interesting results that reflect the understanding of designers and construction executives in Iran concerning the benefits of BIM for performance indicators of construction projects. That is, they assigned the leading roles to the building delivery indices, taking into account time efficiency and building capability, and the relative roles to the construction cost reduction, quality improvement, and sustainable construction indices, which contrasted with the conditions of the construction industry in Iran (i.e., due to low profitability and high failure rates, construction companies adopt new methods and change their traditional approaches such as drawing, modeling, and industrial design to benefit from the unproven return on investment, which prioritizes the value of money over the principles of quality and sustainability. In addition, by prioritizing BIM applications based on KPIs, it was inferred that conflict detection with construction monitoring and monitoring are components of BIM applications to increase quality, and four-dimensional modeling of building information (project scheduling and construction sequence) and construction monitoring have beneficial effects on construction KPIs in Iran.

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