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A New Risk Response Strategy Using Association Rule Mining and Building Information Modeling Capabilities

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ABSTRACT

The dynamic and complex nature of the construction industry leads to increased project uncertainty, exposing construction projects to various risks and hazards. Poor risk management can hinder project objectives. Therefore, implementing effective risk management strategies can enhance project quality, safety, and ensure on-time, under-budget completion. This is achievable when the construction industry adopts cutting-edge methods and tools. Building information modeling (BIM) has been widely used to facilitate project risk management due to rapid technological advancements. Given the significance of risk management in construction projects, this study has proposed a novel BIM-based expert system for addressing project risk responses. Data were collected through a questionnaire, and hidden patterns were discovered using SPSS Modeler software (Clementine) through association rule mining. The Apriori algorithm extracted fifty-three top rules from the dataset based on rule evaluation indexes. Subsequently, an expert system was developed using the extracted rules to address project risks. Finally, the expert system was evaluated by five unbiased experts through a questionnaire. This study can serve as a foundation for addressing project risks using BIM and data mining. Subsequent research can apply this method to other construction projects and compare the results with the present study.

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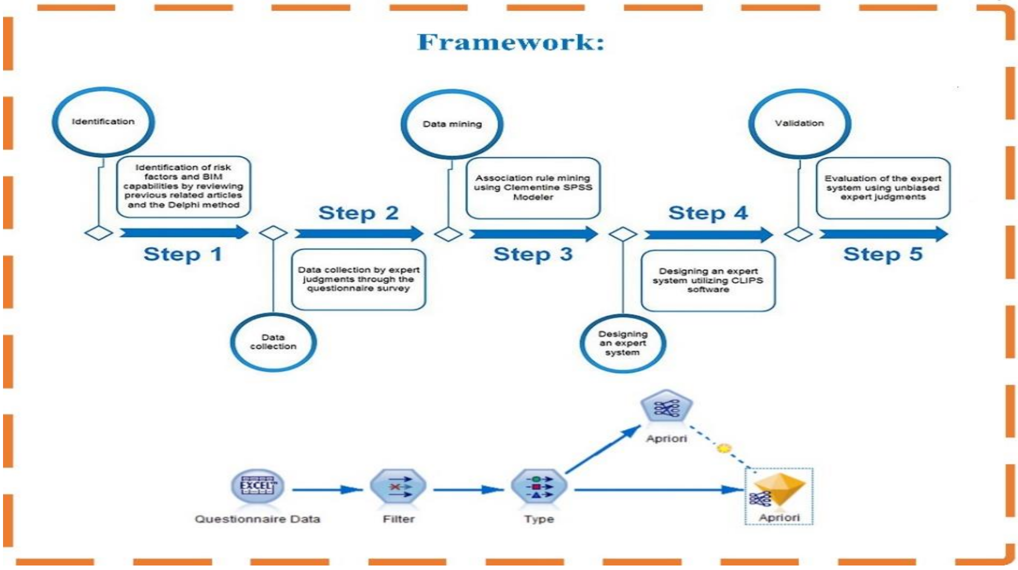
Graphical Abstract



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1. INTRODUCTION

The building industry has been rapidly growing, leading to the creation of large-scale projects with intricate architectures. However, due to the unprecedented scale and complexity, construction projects have become more uncertain and dangerous, resulting in a high bankruptcy rate (1). Therefore, it is essential to include hazard management in project life cycles (2). Various causes can lead to injuries, deaths, property damage, timetable delays, and erroneous cost estimates (3).

Managing risks is a critical aspect of ensuring the success of any project. Errors in risk management can result in delays, budget overruns, compromised safety, and reduced quality. Shockingly, the International Labor Organization reports that construction sites experience an average of 60,000 accidents annually, equating to one fatality every ten minutes. Throughout a construction project's lifecycle, schedule, financial, and legal risks must be managed. In 2014, only 5% of projects in the United States were completed on time, within budget, and met quality standards; according to the US Construction Industry Institute (4), many projects experience delays and increased costs due to unanticipated hazards. Standard risk management methods could be more effective in managing the complex and dynamic nature of modern construction projects. Hence, more innovative approaches are required. Building Information Modeling (BIM) and other risk management solutions have recently emerged as potential solutions. BIM is a comprehensive information system that can assist in managing risks and uncertainties throughout the project lifecycle (5). By using BIM, project managers and decision-makers can respond more quickly and accurately to potential risks, improving the project's chances of success. Therefore, this project aims to develop a BIM-based risk-response expert system to help managers and decision-makers detect and respond to risks more effectively.

2. LITERATURE REVIEW

Construction industry face high level of risk; the seventh PMBOK defines risk as uncertainty. Risks are unpredictable events or conditions that can affect project goals positively or negatively. Positive risks are opportunities; adverse risks are threats (6). Yoe (7) used risk to assess the probability and impact of uncertain future occurrences. Risk and uncertainty pose complex challenges in construction projects, potentially hindering project goals. Thus, project management must include risk management to achieve project goals (8). According to PMBOK, risk management is an integral part of project management. This standard describes risk management as planning, identifying, analyzing, and responding to project risks (6). A suitable risk management approach helps discover, understand, and assess risk variables and their effects. This means it explores the best ways to handle identified hazards. Risk management affects project success (9). These definitions show that risk management can reduce the impact of adverse events and boost positive ones. Despite recent risk management advances, traditional methodologies cannot handle the complexity and dynamism of modern building projects. Traditional risk management has several drawbacks (10, 11):

- The management of knowledge is decentralized and inefficient.
- Communication between the stakeholders and participants is inadequate and should be enhanced.
- Traditional methods are founded on multidisciplinary knowledge and experience. Therefore, they are susceptible to error, time-consuming, and inefficient.

In response to these issues, numerous methods and technologies have been implemented globally for more effective risk management, including building information modeling (BIM). BIM is a cutting-edge technology whose implementation can significantly enhance the construction process throughout the life cycle of a project (12). It is believed to contribute to project data generation, management, and interaction to mitigate risks and maximize interests (13). The National BIM Standard-United States (NBIMS-US) defines BIM as a virtual representation of a building's operational and physical characteristics that leads to better decisions during the project life cycle as a source of knowledge sharing (14). Utilizing BIM throughout the project life cycle can significantly contribute to managing uncertainties and risks during construction projects (3). Expert systems are one of the most attractive and successful fields of artificial intelligence (15). An expert system is a computer system capable of imitating the decisions made by a real-life expert. Such decisions must be made in specialized fields that require expertise. An expert system can make recommendations similar to a consultant. These systems are commonly provided as computer-based systems or software (16). The main components of an expert system are a database of knowledge, an inference engine, and a user interface (17, 18).

Several studies indicate that BIM could benefit the construction industry as a tool for risk management and uncertainty reduction. Tomek et al. (19) examined how BIM affects risk management to support its use in construction. This study examined construction business BIM installation and application hazards. The first group posed severe threats, but the second offered opportunities. Conflict detection and safety planning in BIM could help identify risks. Finally, a practical BIM risk demonstration approach was described. Ding et al.

(20) proposed using ontology and semantic web technology to manage BIM risk management. BIM was created to analyze building hazards. Identifying each risk's main factors, rules, prevention, and repercussions was a plus. However, they discussed construction methods, resources, activities, and procedures that affect project goals. The suggested strategy could have been more time-consuming and could cause problems in large projects. Zou et al. (11) developed a theoretical framework for building the risk breakdown structure (RBS) and a conceptual model for the RBS-BIM link to control bridge project risk. Integrating BIM with conventional risk management techniques could improve efficacy. Malekitabar et al. (21) suggested using BIM to identify safety risks before construction and design. They regulated accident risk and severity guidelines in five high-risk driving groups. Construction accidents could be prevented by identifying risk drivers. Zou et al. (3)examined BIM-related risk management. This study also examined traditional risk management strategies and their problems. They found that BIM may be utilized as a systematic risk management tool and a generator and platform for other risk management tools to detect and analyze risk. Ahmad et al. (22) examined BIM and project risk management. They compared risks before and after BIM using a case study. BIM created additional dangers due to technological and contractual advances. Using BIM in the project lowered and eliminated several high-potential risks. Zou et al. (23) used WBS and RBS to create a BIM risk identification system. They suggested integrating RBS into the BIM platform for dynamic risk identification and risk information management. The recommended method provided several benefits; however, risk detection relied on past experiences. Ur Rehman et al. (5) examined how BIM identifies and manages scheduling risks. Risk factors affecting project scheduling and BIM features were examined to create a feature-factor matrix. A case study assessed the efficacy of the researched aspects. BIM applications have significantly impacted project scheduling performance and helped control hazards. Badran et al. (24) presented a BIM-based risk management methodology for UAE design bid build (DBB) risks. BIM-based risk management frameworks need improvement to manage risks' effects on project costs. Moshtaghian et al. (25) created a BIM risk management framework. This strategy simplified risk identification and showed the need for information integration and timely receipt in project management, especially risk management. Alirezaei et al. (26) integrated a proactive BIM-AR risk management system that includes online cost and schedule risk inspection. BIM and AR could increase risk identification and deliver more thorough and reliable risk assessments.

Table 1 summarizes recent BIM-based risk management research. The importance of risk management and the ineffectiveness of conventional methods have led to many studies on using BIM in project risk management. Previous studies focused on fire, falling, and project phase risks. Because risk management is knowledge-based and involves professionals, employing BIM in project risk management demands their skills. Rare specialists cannot provide rapid consultations due to time constraints. The BIM process in Iran is relatively new, making these abilities more critical than ever. Expert systems are vast repositories of information and experience that can make

TABLE 1. A review of previous research in the field of BIM-based risk management

Research	Contribution	Limitation
Tomek et al. (19)	The implementation of BIM in a construction company was examined to determine its effect on risk management.	The correlation mentioned is unclear and varies based on the project differences.
Ding et al. (20)	Ontology/risk management	Time-consuming method and probable error occurring in large projects
Zou et al. (11)	BIM knowledge and experience integration for risk management by connecting BIM to a tailored RBS	RBS support limitation for quantitative risk analysis
Zou et al. (3)	BIM-based risk management investigation	Examining the general capabilities of BIM for risk management
Ahmad et al. (22)	Creating a framework for automating the risk management process	Manual risk selection and opinion-based probability input
Zou et al. (23)	WBS/RBS linkage to 3D/4D BIM	The database creation related to previous project information
Badran et al. (24)	Developing a conceptual BIM-based risk management framework to manage design-phase risks	Only design-bid-build (DBB) projects were investigated.
Ur Rehman et al. (5)	The role of BIM investigation in identifying schedule risks and providing an effective solution for schedule management	Not using the actual progress date due to the slow progress of the chosen project
Moshtaghian et al. (25)	Introducing a conceptual model to identify and manage risk based on 3D, 4D, and 5D BIM	Permission for data collection was a barrier, as was the time-consuming connection between software outputs.
Alirezaei et al. (26)	The BIM-AR framework was used to enhance onsite project risk management.	The system relied heavily on network connectivity, limiting its use in locations without internet access.

field-specific decisions and intelligently help project decision-makers, like experts. Given the literature analysis, the use of BIM in project risk management, and the benefits of expert systems, this work introduces a novel strategy to integrate BIM technology and expert systems to address the limitations. In this study, a combination of Building Information Modeling (BIM) and association rule mining has been employed to develop an expert system for addressing project risks. Specifically, the Apriori algorithm was utilized to extract frequent patterns and rules from the collected data. These rules have been integrated into the expert system to provide comprehensive solutions for construction project risks. This approach differs from previous research by not only focusing on identifying and responding to risks but also by rapidly generating expert advice and solutions through the integration of association rule mining and BIM capabilities. This innovative strategy addresses the significant need for rapid, expert-driven decision-making in the dynamic environment of construction project risk management, filling a crucial gap identified in the literature.

3. METHODOLOGY

The research methodology consists of five steps, as shown in Figure 1. These are the five steps:
Step 1: Identifying key risk factors and BIM capabilities
Step 2: Data collection using expert judgments
Step 3: Data mining with association rules
Step 4: Designing an expert system
Step 5: Methodology validation
In the following sections, each step is discussed in greater detail.

3. 1. Identifying Key Risk Factors and BIM Capabilities

The first step involves a thorough review of risk management literature to identify key risk factors in construction projects (8, 27-35). Similarly, the capabilities of BIM for responding to risks are discussed in previous works (5, 11, 36-42). After identifying the key risk factors and BIM capabilities from the literature, the Delphi method is employed to further investigate and refine these factors. In Delphi, experts express their views on a given problem and come to a consensus on the solution (43). According to Turoff and Linston (44), the Delphi approach organizes group relations to solve complex problems. This method has some essential characteristics. First, the participants are unknown. Second, it is iterative, and earlier studies suggested 2-10 iterations. Third, it has feedback mechanisms (45). An ideal Delphi panel typically consists of around seven respondents, as this number is manageable while still providing a diverse range of insights (46). In this study, experts are selected through snowball sampling, a non-probability sampling technique where existing study subjects recruit future subjects from among their acquaintances. This method ensures that the panel includes individuals with significant expertise and experience in both risk management and BIM technology.

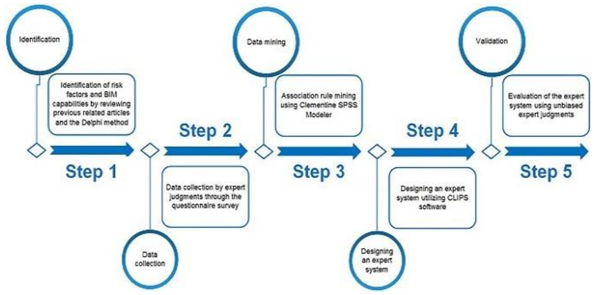


Figure 1. The research methodology

By integrating the insights from the literature review and the consensus from the Delphi method, the study identifies the most pertinent risks and BIM capabilities. This forms the foundation for the subsequent steps in the research methodology, ensuring that the identified factors are both comprehensive and practically relevant.

3. 2. Data Collection Using Expert Judgments

Data collection is a critical step to gather insights and validate the identified risks and BIM capabilities. Researchers have recognized that questionnaires can collect data about views, attitudes, behaviors, and experiences. After identifying risks and BIM capabilities, experts are asked to respond to the questionnaire using snowball sampling. Experts must meet one of the following criteria:

- A minimum bachelor's degree in architecture or civil engineering with five years of experience in BIM.
- A minimum master's degree in architecture or civil engineering with three years of experience in BIM.
- A minimum Ph.D. and a history of research in the field of BIM and risk management.

3. 3. Data Mining with Association Rules

Association rule mining is a data mining application that has not been extensively utilized in risk management, though it is widely known as market basket analysis. Association rule algorithms search for patterns that frequently occur in datasets. The goal of association analysis is to find interrelated characteristics and extract rules from these features. The extracted rules are expressible as "if..., then...," and each has three measurements: support, confidence, and lift (47, 48). Generally, association rules identify attractive associations within a database of items (49).

Let $I = \{i\_1. i\_2. i\_3. \dots\ i\_m\}$ be an itemset and $U = \{U\_1. U\_2. U\_3. \dots . U\_M\}$ be a database and U⊆I. The general form of a rule is defined as follows (49):

$$X \Rightarrow Y \tag{1}$$

$$X \subset I, Y \subset I, X \cap Y \neq \emptyset \tag{2}$$

where X and Y represent database item sets.
Three measures evaluate association rules:
1) The Support measure: It measures the portion of database transactions involving both X and Y. The value varies from 0 to 1.

$$Support\ (X \rightarrow Y) = p(X \cup Y) = \frac{Sup_{count(X\cup Y)}}{Sup_{count(D)}}, \text{Support domain}=[0,1] \tag{3}$$

2) The Confidence measure: It measures the degree of interdependence between X and Y. This means that a set of transactions containing X may include Y at a certain probability. The value ranges from 0 to 1. A significant confidence measure would be more desirable.

$$Confidence(X \rightarrow Y) = p\left(\frac{X}{Y}\right) = \frac{Sup_{count(X\,Y)}}{Sup(X)}, \text{Confidence domain}=[0,1] \tag{4}$$

3) The Lift measure: This measure represents the correlation between rules. In other words, It indicates the degree to which a rule is better than its absence. The value could range from zero to infinity.

$$Lift(X \rightarrow Y) = Sup(X \cup Y)/(Sup(X) \times Sup(Y)), \text{Lift domain}=[0,\infty) \tag{5}$$

There is a tendency for the rule to be weak when the lift measure is less than 1. The antecedent and consequent are independent when the lift measure is 1. If the lift measure exceeds 1, then the rule is suitable. A rule's attractiveness can be estimated by its confidence and lift measures (48). Apriori algorithms are the basis for most association rule approaches, which Agrawal and Srikant (50) introduced in 1994. This is a bi-level search algorithm in which searching occurs at the second level after completing the first. The Apriori algorithm finds all the frequent single-item sets. Then, the frequent two-item sets are found before constructing three-item sets. The process continues until no larger frequent item set is found (47). This study used the Apriori algorithm to mine rules using SPSS Clementine Modeler Software.

3. 4. Designing an Expert System

An expert system is created using CLIPS software. CLIPS Software is a tool for creating and managing rule-based systems, including knowledge representation, inference, and reasoning. It automatically triggers rule firing based on defined conditions when new facts are asserted or existing ones are modified through pattern-matching.

3. 5. Methodology Validation

Five unbiased experts assess the expert system and its outcomes based on recent studies like Ghousi et al. (51) and Eken et al. (52). Experts should have experience in risk management and BIM technology. Hence, they evaluate the methodology's strengths and weaknesses through a questionnaire.

4. IMPLEMENTATION AND RESULTS

In this section, we illustrate the application of the methodology practically, which comprises five steps described in section 3.

4. 1. Identifying Key Risk Factors and BIM Capabilities

Experts in the construction industry identified the risk factors and BIM capabilities with a general and comprehensive view of Iranian construction projects. This study included nine experts from the construction and academic communities with experience in risk management and BIM technology. The Delphi technique and snowball sampling were used, as explained in section 3.1. In the first Delphi round, BIM capabilities and risks were identified based on the literature review. Experts were asked to comment on factors not listed. Ultimately, seventeen risks and twelve BIM capabilities were identified by the end of the second round.

In general, risks can be classified into internal and external categories. The project management team usually controls internal risks, not external ones like political, cultural, and social risks (34). Thus, only internal risks were considered. Figure 2 shows seventeen risks in four main categories: planning and design, construction, safety, and management. Twelve BIM capabilities are illustrated in Table 2.

4. 2. Data Collection Using Expert Judgments

Data analysis, demographic characteristics, and the results of the data analysis were summarized in this

TABLE 2. BIM capabilities

No.	BIM application
B1	Clash detection
B2	5D Cost estimation
B3	Construction scheduling
B4	Visualization
B5	Automated Compliance Checking
B6	Common Data Environment
B7	Time-space conflict analysis using 4D
B8	What-if Scenario analysis using 4D
B9	BIM-VR integration
B10	Site layout planning
B11	Interoperability
B12	Safety training (BIM-VR-AR integration)

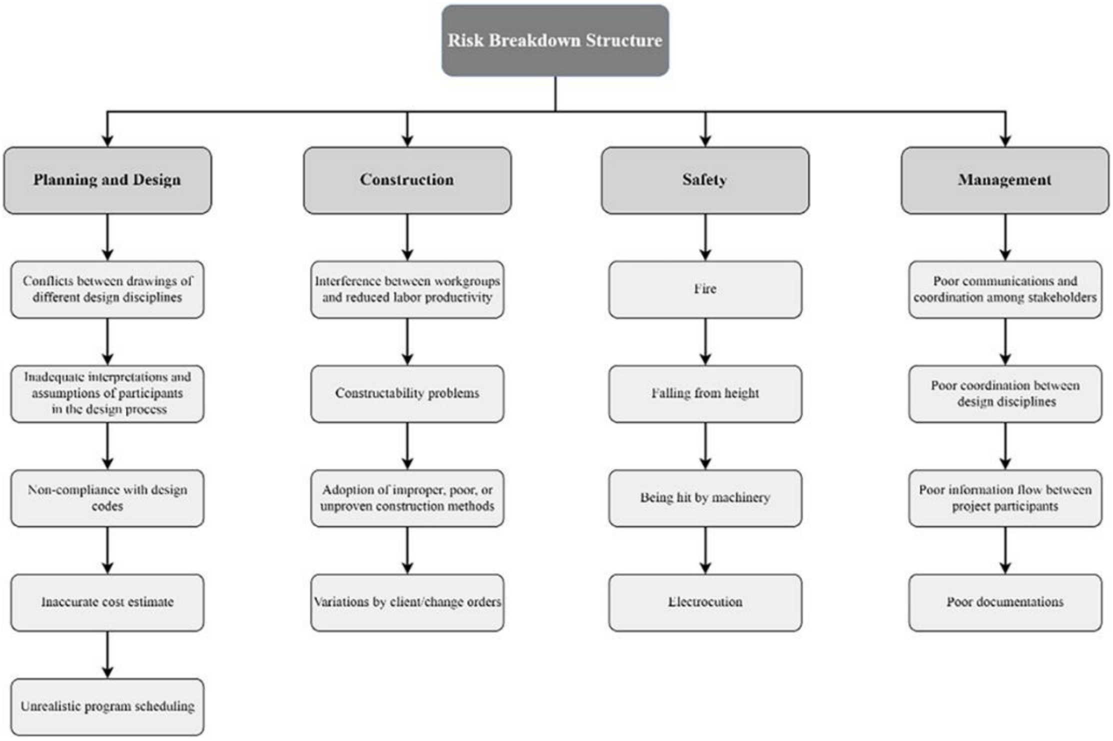


Figure 2. The Risk Breakdown Structure

section. The questionnaire was distributed among 24 experts using the snowball sampling technique, and they completed it according to section 3.2. Expert profiles are displayed in Figure 3.

The scoring strategy was as follows: experts were asked to choose the most efficient BIM capability for one and a combination of risks based on a matrix of risks and BIM capabilities. Data reliability was obtained through various methods, including Kuder-Richardson 20 (KR-20). Kuder-Richardson's value in this study was 0.82, which indicates suitable internal consistency. Finally, the score sheet in Excel software format was generated. Hence, rule mining could be undertaken in the next section.

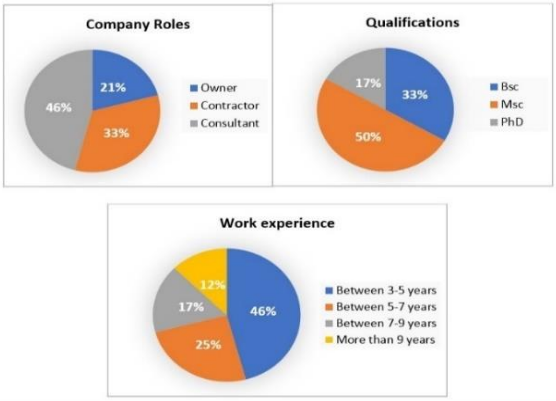


Figure 3. Expert profiles

4. 3. Data Mining with Association Rules

First, the data were accumulated using the questionnaire. Then, the data preparation, preprocessing, and cleaning operations were performed. The purpose of these steps was to improve the quality of the data and the model output. Data were accumulated in an Excel file. SPSS Clementine Modeler Software was used to generate the model and extract the rules using the Apriori algorithm. Thus, the data from the Excel file were imported using the Source node in the SPSS Modeler software. Next, unnecessary data were removed using the Filter node. Following this step, the Type node was used to determine the data type and whether it was input or output. Finally, the best rules were extracted using the Apriori algorithm based on the rule evaluation indexes (Minsup, Minconf, and Lift). Notably, experts determined Minsup=0.05, Minconf=0.75, and Lift>1. Figure 4 illustrates the process of rule extraction in SPSS Clementine Modeler software.

As a result, 53 rules were derived from the best governing rules, as summarized in Tables 3 and 4. Table 3 displays the response to each risk, and Table 4 shows the response to two combined risks.

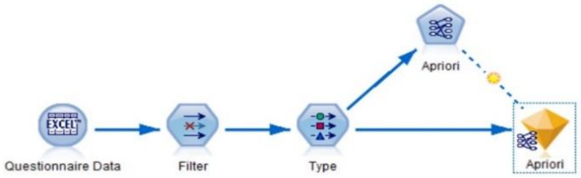


Figure 4. The process of rule extraction in SPSS Clementine Modeler Software

For instance, rule 1 states that clash detection, as a BIM capability, provides the best response to the risk of conflicts between the drawings of different design disciplines, with a confidence level of 95.8% and a lift value of 4.26.

Rule 1 in Table 4, with a confidence of 95.83% and a lift of 4.84, indicates that safety training based on BIM and VR/AR integration is the best risk response if fire and falling from height risks coincide. Also, another rule with a confidence level of 86.95% and a lift value of 4.32 explains that if the risk combination of "variations by client /change orders" and "adoption of improper construction methods" occurs, then the best risk response is BIM-VR integration.

TABLE 3. Extracted Rules for individual risks

No.	Antecedent	Consequent	Confidence%	Lift
1	Conflicts between the drawings of different design disciplines	Clash detection	95.8	4.26
2	Adoption of improper construction methods	What-if Scenario analysis using 4D	95	4.5
3	Inadequate interpretations and assumptions of participants in the design process	BIM-VR integration	91.7	3.21
4	Fire	Safety training (BIM-VR/AR integration)	91.6	4.5
5	Interference between workgroups and reduced labor productivity	Time-space conflict analysis using 4D	91.31	5.34
6	Variations by client /change orders	BIM-VR integration	91.31	3.19
7	inaccurate cost estimate	5D Cost estimation	90.47	7.32
8	Poor documentation	Common Data Environment	89.5	3.8
9	Inadequate interpretations and assumptions of participants in the design process	Visualization	88.6	2.83
10	Being hit by machinery	Site layout planning	87.6	3.9
11	Constructability problems	Time-space conflict analysis using 4D	87.5	5.12
12	Falling from height	Safety training (BIM-VR/AR integration)	87.5	4.34
13	Fire	BIM-VR integration	87.4	3.1
14	Falling from height	Automated Compliance Checking	87.1	2.68
15	Interference between workgroups and reduced labor productivity	Site layout planning	86.96	3.87
16	Variations by client /change orders	Visualization	86.96	2.81
17	Poor communication and coordination among stakeholders	Common Data Environment	86.37	3.72
18	Constructability problems	Clash detection	83.33	3.71
19	Non-compliance with design codes	Automated Compliance Checking	83.33	2.55
20	Falling from height	Site layout planning	83.15	3.71
21	Unrealistic program scheduling	construction scheduling	82.6	3.71
22	Poor information flow between project participants	Common Data Environment	82.5	6.25
23	Poor coordination between design disciplines	Common Data Environment	80.2	3.56
24	Fire	Site layout planning	79.16	3.41
25	Poor information flow between project participants	Interoperability	78.26	3.52
26	Electrocution	Safety training (BIM-VR/AR integration)	77.19	5.52
27	Poor coordination between design disciplines	Clash detection	76.1	3.34
28	Being hit by machinery	Safety training (BIM-VR/AR integration)	75.9	3.72
29	Fire	Automated Compliance Checking	75	2.29

TABLE 4. Extracted Rules for two-risk combinations

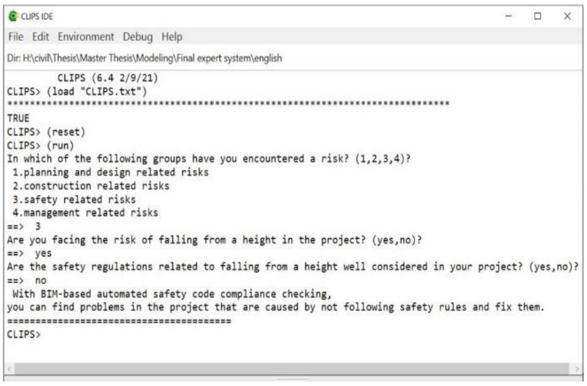
No.	Antecedent	Consequent	Confidence%	Lift
1	Fire and falling from height	Safety training (BIM-VR/AR integration)	95.83	4.84
2	Fire and being hit by machinery	Site layout planning	93.8	4.2
3	Fire and Electrocution	Safety training (BIM-VR/AR integration)	92.5	4.8
4	Falling from height and Electrocution	Safety training (BIM-VR/AR integration)	91.83	4.84
5	Poor information flow between project participants and Poor documentation	Common Data Environment	91.65	5.01
6	Interference between workgroups and reduced labor productivity and Constructability problems	Time-space conflict analysis using 4D	90.9	3.62
7	Constructability problems and Adoption of improper construction methods	What-if Scenario analysis using 4D	87.5	3.7
8	Variations by client /change orders and Adoption of improper construction methods	BIM-VR integration	86.95	4.32
9	Falling from height and being hit by machinery	Site layout planning	86.36	3.87
10	Falling from height and Electrocution	Site layout planning	85.71	3.87
11	Poor coordination between design disciplines and Poor communications and coordination among stakeholders	Common Data Environment	85.3	4.78
12	Interference between workgroups and reduced labor productivity and Constructability problems	Site layout planning	83.33	3.68
13	Constructability problems and Variations by client /change orders	What-if Scenario analysis using 4D	83.33	3.54
14	Fire and falling from height	Site layout planning	82.7	3.68
15	Fire and being hit by machinery	Time-space conflict analysis using 4D	81.1	3.29
16	Fire and Electrocution	Automated Compliance Checking	80.5	3.47
17	Poor coordination between design disciplines and Poor information flow between project participants	Common Data Environment	79.9	4.55
18	Variations by client /change orders and Adoption of improper construction methods	What-if Scenario analysis using 4D	79.16	3.51
19	Poor communications and coordination among stakeholders and Poor documentation	Common Data Environment	78.5	4.32
20	Conflicts between the drawings of different design disciplines and Non-compliance with design codes	Automated Compliance Checking	77.8	3.1
21	Fire and falling from height	Time-space conflict analysis using 4D	77.1	2.96
22	Poor coordination between design disciplines and Poor documentation	Common Data Environment	76.7	4.1
23	Falling from height and being hit by machinery	Time-space conflict analysis using 4D	75.6	2.8
24	Fire and Electrocution	Site layout planning	75	3.13

4. 4. Designing An Expert System

The expert system was created using association rules based on expert knowledge. For this purpose, forward chaining was defined as an inference strategy. CLIPS software was used to write the related codes. For instance, Figure 5 depicts the user searching for a suitable response to the risk of falling from height in the expert system.

4. 5. Methodology Validation

The presented approach was evaluated by five unbiased experts, as stated in section 3.5 (51-53). All experts had experience in risk management and BIM technology. During a meeting, experts were asked to evaluate the methodology's strengths and weaknesses. Participants affirmed the importance of BIM in project risk management and agreed that similar expert systems could facilitate future risk management. Furthermore, they emphasized that construction companies can differentiate themselves from the competition by utilizing new technologies, such as BIM, in risk management.



```
         CLIPS (6.4 2/9/21)
CLIPS> (load "CLIPS.txt")
********************************************************************************
TRUE
CLIPS> (reset)
CLIPS> (run)
In which of the following groups have you encountered a risk? (1,2,3,4)?
 1.planning and design related risks
 2.construction related risks
 3.safety related risks
 4.management related risks
==>  3
Are you facing the risk of falling from a height in the project? (yes,no)?
==>  yes
Are the safety regulations related to falling from a height well considered in your project? (yes,no)?
==>  no
 With BIM-based automated safety code compliance checking,
you can find problems in the project that are caused by not following safety rules and fix them.
========================================
CLIPS>
```

Figure 5. Searching risk responses in the proposed expert system

Furthermore, Experts agreed that the proposed method could assist decision-makers in risk management processes and produce BIM-based responses. Its simplicity was also appreciated since most project managers have limited time and can only spend a short time learning and using it. They recommended developing an automated data-gathering system, extracting rules, responding to risk, and producing a web-based system that could be accessed from anywhere, anytime, and on any device for future research. Finally, respondents rated the following statements from 1 to 7, as shown in Table 5.

5. DISCUSSION

Interesting results can be obtained by considering Tables 3 and 4. For instance, the risk of conflicts between design disciplines in construction projects, particularly in developing countries, can be minimized through clash detection. Employers should be aware of this issue and consider the incurred cost (rule 1 in Table 3). The client's lack of understanding of the space, interior view, and location causes problems when they change the agenda and plans. Rule 6 in Table 3 suggests using BIM-VR integration to mitigate the risk of client-driven changes. Based on rule 12 from Table 3, the risk factor of falling from height can be mitigated by safety training through the BIM-Extended Reality (XR) integration. Falling from height is a common accident in construction sites, causing many casualties annually. Training workers using BIM-XR, especially VR, can provide a fully immersive experience and enhance their skills through continuous practice. Also, the risk of poor communication and coordination among stakeholders can be reduced using the Common Data Environment application with Power BI or SQL server software (rule 17 in Table 3).

TABLE 5. Unbiased experts' responses to the questionnaire survey

Questions	Respondents					The mean score
	1	2	3	4	5	
The search mechanism was well-designed and valuable	5	4	6	7	5	5.4
A user-friendly and appropriate process was used to input risk data for construction projects	6	5	5	4	4	4.8
Rules were generated rationally and practically	5	5	7	5	6	5.6
BIM capabilities generated sufficient and valuable data for efficient risk management.	5	5	5	6	4	5
The BIM-based expert system for project risk management was generally valid and may positively affect construction project risk management	6	7	6	6	5	6

A combination of two risk factors and their response are shown in Table 4. For example, when interference between workgroups and constructability problems happens, the reasonable response is time-space conflict analysis using 4D due to scheduling adjustments (as specified in rule 6 in Table 4). Rule 7 in Table 4 states that the risk response to a combination of constructability problems and improper construction methods is a what-if scenario analysis using 4D. Rule 20 in Table 4 also recommends automated compliance checking as the best response to conflicts between the drawings of different design disciplines and non-compliance with design codes.

Although BIM has become widespread in the past decade, developing countries such as Iran still face challenges in convincing employers of the necessity of various BIM applications. Accordingly, it is crucial to consider risk factors and combinations to demonstrate the most appropriate BIM application and its associated costs to employers.

6. CONCLUSION

This research developed an expert system using BIM for project risk management, particularly for risk responses. Accordingly, engineers, decision-makers, and project managers could manage and respond to risks appropriately in a new way. The literature review indicated that BIM could be used in various risk management applications. BIM technology can better manage scheduling, design, construction, safety, and risks. The proposed approach uncovered concealed patterns using association rule mining and BIM capabilities. Fifty-three significant rules were extracted using the SPSS Modeler software (Clementine). The results showed that the Apriori algorithm was suitable for rule extraction because it performed well, had a fast response time, and extracted many rules. Therefore, the expert system's knowledge storage made it possible for decision-makers to choose the correct response more quickly and accurately.

Nevertheless, there are some limitations, including that the results were based on expert opinion and could not be generalized. Future research should focus on implementing the suggested method in large-scale construction projects and developing the expert system for automating data collection, mining, and rule extraction. Moreover, text mining can be used to analyze documents and letters. Thus, a BIM-based risk management system can automatically identify and search for risk factors.

7. DECLARATION OF COMPETING INTEREST

The authors declare no financial interests/personal relationships which may be considered as potential competing interests.

8. FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

9. DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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Persian Abstract

چکیده

ماهیت پیچیده و پویای صنعت ساخت سبب افزایش ریسک‌ها در پروژه‌ها شده است، ازاین‌رو مدیریت مؤثر ریسک به‌منظور بهبود کیفیت، ایمنی و اجرای موفقیت‌آمیز پروژه در زمان و بودجه برنامه‌ریزی شده بسیار حائز اهمیت می‌باشد. استفاده از روش‌ها و فناوری‌های به‌روز انقلاب صنعتی چهارم، می‌تواند کمک فراوانی به رفع مشکلات ساخت‌وساز سنتی نماید. مدل‌سازی اطلاعات ساختمان (BIM) به‌طور گسترده‌ای برای تسهیل مدیریت ریسک پروژه به دلیل پیشرفت‌های سریع فناوری مورد استفاده قرارگرفته است. در این پژوهش یک مدل پیشنهادی با استفاده از مدل‌سازی اطلاعات ساختمان (BIM) و قوانین تلازمی به‌منظور پاسخ‌دهی به ریسک‌های پروژه ارائه شده است. لذا در ابتدا داده‌های موردنیاز(کاربردهای BIM و ریسک‌های پروژه) بر اساس نظر خبرگان و در قالب پرسشنامه جمع‌آوری گردید. سپس با پیاده‌سازی قوانین تلازمی در نرم‌افزار SPSS Modeler، ۵۳ الگوهای پنهان داده‌ها به‌منظور پاسخ‌دهی به ریسک‌ها با توجه به کاربردهای BIM کشف و در قالب یک سیستم خبره توسعه داده شد. درنهایت سیستم خبره طراحی‌شده به‌وسیله پنج خبره بی‌طرف اعتبارسنجی شد و مورد تائید قرار گرفت. در مطالعات آتی با ترکیب روش پیشنهادی و سیستم پشتیبان تصمیم‌گیری (DSS)، می‌توان ریسک‌ها را به‌صورت کاملاً خودکار مدیریت نمود.