Preprints.org

Article

Not peer-reviewed version

# BIM-Based Risk Management to Optimal Performance in Construction Projects

Khaled Jameel Aladayleh * and Mohammad J Aladaileh

Posted Date: 23 October 2024

doi: 10.20944/preprints202410.1783.v1

Keywords: Risk management (RM); Building information modeling (BIM); Construction project; Analytical Hierarchy Process (AHP); optimal performance

Preprints.org is a free multidisciplinary platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This open access article is published under a Creative Commons CC BY 4.0 license, which permit the free download, distribution, and reuse, provided that the author and preprint are cited in any reuse.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1

Disclaimer/Publisher's Note: The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

buildings MDPI

*Type of the Paper (Article)*

# BIM-based risk management to optimal performance in construction projects.

**Khaled Jameel Aladayleh [1, *], Mohammad J Aladaileh [2]**

[1]Doctoral School, Universidad Politècnica de València, València, Spain; khaalja@doctor.upv.es
[1] Mutah university, Jordan; khalid57@mutah.edu.jo
[2]Universidad de Salamanca, Salamanca, Spain,; aladaileh.mohd@usal.es
* Correspondence: khaalja@doctor.upv.es

**Abstract:** This study explores integrating Building Information Modeling (BIM) technology into risk management practices for construction projects, aiming to enhance project performance through improved risk identification, assessment, and mitigation. The research employs the Analytical Hierarchy Process (AHP) to prioritize BIM-based strategies across multiple risk management dimensions, including technical, financial, sustainability, and time management. The findings demonstrate that BIM-financial strategies rank most among BIM-driven risk management, followed by sustainability and time. In contrast, Technical, Operation, and maintenance capabilities have the lowest rank. Given the high priority of BIM financial strategies, it has been applied to conduct sensitivity analysis; the sensitivity analysis results demonstrate the dynamic nature of BIM sub-criteria strategy in response to changes in the weight of financial considerations. As financial concerns diminish, the shift towards sustainability, health, safety, and time efficiency underscores the importance of a more balanced approach in BIM strategy prioritization. BIM- risk management improves project outcomes by enabling real-time data-driven decision-making, enhancing stakeholder collaboration, and optimizing resource use, cost control, and sustainability. This research contributes to theoretical and practical advancements in construction risk management, suggesting that BIM can be a transformative tool for optimizing project performance while addressing the complexities and uncertainties inherent in the construction industry.

**Keywords:** Risk management (RM), Building information modeling (BIM), Construction project, Analytical Hierarchy Process (AHP), optimal performance.

**Citation:** To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Received: date
Revised: date
Accepted: date
Published: date

**Copyright:** © 2024 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

## 1. Introduction

Since the 17th century, "risk" has been used to describe hazardous threats and their repercussions [1-3]. Siegrist and Árvai [4] define risk as the likelihood of financial loss due to unfortunate events affecting the institution's finances. Alaeddini and Dogan [5] and Zou et al. [3] define 'the probability of unwanted risks and the accompanying repercussions' as prospective Risks and their effects. Construction projects involve planning, designing, building, operating, and decommissioning, each with risks [6-8]. Structural complexity, new building technologies, and rapid growth increase risks [9].

© 2024 by the author(s). Distributed under a Creative Commons CC BY license.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



Logical and methodical risk management requires early identification and risk assessment methods [10]. However, traditional risk management methods are ineffective [11,12]. Zou et al. [3] say risk management occurs throughout building projects. The many common threats that matter are complex to resolve [13]. The risk may increase with an insufficient database, subjective views, and time and cost constraints [14]. Without advanced data analysis techniques made possible by digital technology, these concerns may be more challenging to manage and research [15-17]. According to Azhar et al. [18] and Liu et al. [19], well-planned and managed risks increase project success. A risk event may affect project success or failure. However, companies can mitigate these risks [20, 21]. Given the unpredictable nature of construction and the significant influence risk management has on project completion, this area may considerably benefit from the risk management process [22]. Simultaneously, the construction sector, a significant contributor to GDP in numerous nations, faces challenges that might adversely affect project outcomes [1]. Construction operations involve many stakeholders, resource availability, environmental issues, budgetary constraints, political dynamics, low productivity, and contractual obligations, which might slow project progress [23]. According to Eilers et al. [24] and Aladayleh [25], successful initiatives require time, cost, quality, and performance. Price increases and scheduling delays are the biggest challenges in the construction industry [10].

Azhar [18] believes formal risk management for building projects provides essential data and evaluations. Complexity impacts building projects [26, 27]. These risks affect project outcomes [28]. Recent studies link construction to delays [10]. This causes owner-contractor mistrust, lawsuits, and project abandonment (16,17]. Risk increases affect construction time, cost, quality, and safety [25, 27, 29]. Due to heightened risks, construction projects have cost overruns of 20.4% to 44.7%, with nine out of ten globally [26, 29]. Risks include structure damage, injury, mortality, budget overruns, and construction delays [10, 28]. These issues stem from design problems, including inadequate load-bearing capacity, material failures like concrete mix anomalies, ignorant clientele, and poor management [3,30]. Middle East construction, especially Jordan, needs aid with risks and challenges due to 40% execution failures. [31]. Corruption, low technical capabilities, limited member knowledge, competition, lack of R&D, weak real estate market, business delays, bureaucracy, inflation, and land acquisition issues plague the Jordanian construction sector. Politics and economy limit Jordan's infrastructure investment [23,32,33].

This paper conceptually outlines BIM's risk management and construction performance benefits. The study examines how BIM might reduce risks and losses throughout the construction life cycle while addressing the constraints and tasks of traditional BIM. Construction benefits from better performance. BIM's superior digital technology helps coordinate projects throughout a facility's lifecycle [33]. Construction risk management is easier using BIM. BIM helps manage risk [7]. Yang & Mao [34] mention that BIM may collect substantial data on a facility's physical and functional

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



elements throughout its life cycle. Darko et al. [35] claim that data reduces danger and enhances building.

In BIM-based risk management, digital technologies reduce project risks [36,37]. Construction project inefficiencies, losses, and interruptions are reduced via BIM risk management [20,31,38]. BIM offers improved risk management capabilities. Nonetheless, no comprehensive frameworks integrate BIM with traditional risk management [32,33]. Research is required for methodologies that effectively integrate these domains. Current BIM-based risk management technologies predominantly overlook human factors [27]. These instruments must be analyzed for ease of use by construction professionals. BIM-based risk management systems are frequently untested and inadequately assessed in construction projects. These tools must be evaluated practically to ascertain their effectiveness and reliability. Construction risk management encompasses various methodologies owing to its intricacy [4-6]. There is limited research on integrating BIM with other technologies and disciplines to enhance risk management, such as the Internet of Things, artificial intelligence, and machine learning. Data precision and security are crucial for risk management [3].

Research is required on BIM-based data management challenges, such as interoperability, security, and privacy[7]. The absence of established standards and regulations renders BIM-based risk management intricate [14-16]. Research ought to yield industry-wide standards and guidelines for consistent and effective implementation. Addressing these research deficiencies may enhance BIM-based risk management and the productivity of building projects.

Risk management using BIM is a reality in construction. The trip is not over. What remains is to close the conceptual, experimental, and contextual gaps that prevent contractors from maximizing BIM risk management advantages. Only BIM-based best practices may improve conventional risk management from its unacceptably poor productivity to greatly optimized material advantages. This study prioritizes BIM-based risk management research requirements from the literature and technical knowledge to fill this gap. The result is a collection of key study problems that, when addressed by future research, may enable contractors to utilize BIM for risk management not as an assurance but as a dependable way to increase construction risk management productivity.

The construction industry is characterized by high volatility or uncertainty, often caused by design complexity, market dynamics, innovative technology, and human factors. These uncertainties threaten the success of construction projects, necessitating a diligent and efficient management strategy. Construction risks can take the form of project resources such as time, cost, and quality, or business market, credit, and corporate risks, depending on the nature of the attributes. Regardless of the focus, risk management is a common decision-making practice in various fields of study. However, the choice of risk response is complicated by the interdependence or conflict between responses, context, and project stakeholders. Given these characteristics of construction risks, identifying risks during the project concept phase would facilitate using advanced project

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



management techniques. It would improve decisions regarding setting project objectives. The primary aim of the research is to determine the feasibility of BIM-based risk management for improving performance in the construction industry.

The specific objectives of this research are (1) to assimilate knowledge from the risk management literature to develop a BIM-based risk management framework for identifying, assessing, and managing appropriate risk responses for the construction industry; (2) Investigate the opportunities that present themselves to the construction industry when adopting risk management practices using BIM technologies and methods; (3) Analyze and evaluate the benefits and limitations.

## 2. Literature Review.

Construction dominates Middle Eastern and Jordanian economies. Jordan needs innovative construction management methods to grow this industry nationally and globally. Development plans in Jordan recommend BIM for construction. Hyarat et al. [33] noted that the Jordanian Society of Engineers offers BIM training, which may increase BIM adoption. For 3D visualization, Jordanian construction design offices use BIM to improve efficiency and cost, facilitate interdisciplinary collaboration and coordination, detect clashes, evaluate energy and performance, implement intelligent objects, and perform audits [33 Mohammed and Haron [32] say contract responsibilities and project party interaction, coordination, and interoperability drive BIM implementation in Jordan.

Recent global developments use BIM. A 2010 McGraw Hill study found that 74% of Western European BIM users saw a significant ROI. Many BIM integration strategies for construction risk management have been studied. Ganbat et al. [20] reviewed 526 BIM-based risk management studies from 2007 to 2017. Safety, building process simulation, supply chain optimization, and defect prevention were prioritized. BIM implementation, maintenance, and cost overruns were financial concerns. The study correlated investigations to reduce BIM-based structure risks.

Practical BIM implementation for automated identification and risk assessment is well-studied. Zhou et al. [39] detected construction site safety issues using rule-based logic and BIM models. Falls, structural issues, electrical dangers, and bodily damage can be detected autonomously. Researchers built a BIM model expert system to analyze fall, accident, and pothole hazards [19]. Visual and analytical system data enhances risk management. Much research has identified construction hazards using 4D BIM. Hamledari et al. [40] evaluated construction schedule uncertainty using discrete event simulation and 4D BIM. Risk register-based 4D modeling assessed activity delays and cost overruns [41]. Risk response and mitigation have improved using 4D models and risk data [42]. Researchers created BIM-based building supply chain risk reduction [43].

Darko et al. [35] recommended combining Radio Frequency Identification (RFID) and Global Positioning System (GPS) to track material delivery in real time and increase supply chain visibility. Jalaei and Jrade [44] assessed building supply chain network risks using BIM and social network analysis. Many studies have studied BIM for construction quality and defect management. Pickering and Byrne [45] suggested BIM-enabled seismic risk assessment and mitigation. The researchers also used BIM to improve earthquake and flood resilience building designs, reducing their effects. BIM-based risk management works, but its implementation needs improvement. Interoperability, data reliability, model accuracy, and organizational integration must be addressed. To maximize BIM-based risk management benefits, frameworks, standards, and best practices must be developed [35].

Construction projects require risk management to regulate cost, time, safety, and quality [10,30]. The researchers employed the Analytic Hierarchy Process (AHP) in Egypt and Saudi Arabia to prioritize risks during the bidding and construction phases. Expert

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



questionnaires indicated that financial risk was the most prevalent, succeeded by design, political, and construction dangers. The Analytic Hierarchy Process (AHP) was streamlined using Expert Choice Software ECS [30]. Musarat et al. [27] used AHP in Malaysia. They found that BIM and integrated systems had the best potential as advanced technologies, with a score of 0.3855, followed by wireless monitoring and sensors at 0.3509. Industrial Revolution 4.0 technology like robotics, automation, BIM, augmented reality, and wireless monitoring promise to improve worker health and safety in the construction industry. Robin et al. [46] used the Analytical Hierarchy Process to evaluate twenty participants' BIM competencies. Critical performance metrics were policies (37%), procedures (17%), technology (16%), people (15%), and organization (15%). Moshtaghian and Noorzai [21] illuminated the integration landscape in project management and stressed the importance of timely information integration, particularly in risk management. They presented a database to analyze timely risk management influences using 3D, 4D, and 5D models. Alirezaei et al. [47] proposed an online project risk monitoring system using BIM and Augmented Reality (AR). 67% of consumers cited better communication, punctuality, and risk awareness.

Dey [11] offered historical background for an Indian oil pipeline project and illustrated AHP and decision tree risk management. This technique separated the project into work packages, assessed hazards, and measured their consequences. Al-Fahad and Burhan [28] linked risk management to BIM using the Fuzzy Analytical Hierarchical Process (FAHP) to analyze risks and create pricing estimates for specific categories. Their study found that BIM-integrated systems may lower most risk factors, highlighting the need for procedural solid and training requirements. Hamid and Zainon [48] created a BIM model for a complicated Malaysian airport project that facilitated risk analysis and stakeholder engagement, decreasing change orders by 30% and finishing two months early. A BIM-based 3D model by Fernández-Alvarado et al. [49] identified future disagreements and improved stakeholder communication, lowering safety incidents by 40% in an urban infrastructure upgrade project.

Sanchez et al. [50] used BIM to reduce risk during the Sydney Opera House renovation, while Smith [14] used BIM to improve visualization and planning for the London Cross Rail project. BIM managed design coordination throughout the World Trade Center building, enabling efficient planning and safety compliance [51]. These examples demonstrate BIM's ability to improve construction risk management and project outcomes. These studies and implementations show that BIM is a transformative tool for risk management and project success in the construction industry. Numerous research studies have examined BIM and related technologies in construction risk management. However, most evaluations focus on specific aspects of these technologies' applicability, evolution, and limitations [52]. Many academic papers assess traditional risk management methods, while others briefly discuss BIM's pros and cons [46]. There is no comprehensive analysis of recent BIM-based risk management research, digital technology, or traditional risk management methodologies. This paper addresses this gap by highlighting the main benefits of BIM in risk management, such as improving construction project efficiency and encouraging further research.

### *2.1 Risk Mitigation in Construction Projects Using BIM.*

BIM enables high-efficiency construction management, simplifying and improving industry knowledge [1]. BIM models are created from digital structure simulation models and laser-scanned images in three to n dimensions. Alaeddini & Dogan [5] say completed models communicate process data and operate. BIM is needed to overcome the main limitations of 2D (axonometric and aerial view) and 3D (axonometric and perspective) construction representations [3]. BIM models all building parts over time. BIM positions and shows nD model accessories and structures. Status updates, executive reports, construction progress meetings, and project data are needed [9]. Data assesses risk and impact [7]. Data flaws and risks are highlighted. Proactive risk decision-making requires judgment

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



or experience [1]. Risk assessment of data reports requires creativity and expertise. Companies must disclose building project portfolios [10, 60]. Data processing, inspection, and proactive risk management are neglected. The firm must prioritize it with senior management approval [16,17, 29]. The most progressive people recognize financial challenges or opportunities in the established environment as risk management improves performance preparation [17]. BIM anticipates issues and evaluates building component readiness throughout the project [53]. BIM simulates work area mobility, construction processes, and personnel, helping schedulers optimize logistics [19]. BIM improves risk assessment. The correlation between structural and maintenance data is crucial for risk assessment. Chowdhury et al. [54] say BIM integration aids structural understanding and risk identification.

Risk management is improved by BIM's risk analysis report, which provides specific views of buildings and infrastructure [55]. It can also streamline stakeholders' evaluations and help them eliminate mismatches [19, 34]. Finally, reliable design and construction information reduces formalities and access time [20,35]. BIM stores countermeasure and recovery data for building, operating, and maintaining facilities [31, 56]. Hazard, risk probability, building damage, and other structured data are integrated into BIM to automatically analyze risk and open chart risk system architectural component information.

Many BIM tools help project managers manage risks [3,53]. Active methods like BIM help digitize plans [57, 58]. Parsamehr et al. [36] say BIM's 3D visualization helps stakeholders quickly identify and delete unneeded design elements, reducing risks. BIM centralizes project data, improving drawing flow and management. BIM's precise quantity takeoffs and estimating tool integration eliminate calculation errors [24, 61]. BIM integrates with GIS and other data sources to simplify site analysis, reducing the risk of insufficient site investigations during planning and design [3, 20, 59]. BIM can preserve risk-related information and share project experiences while minimizing risks during design and construction [37, 62].

According to the research model presented in the literature review, after final confirmation of the practical criteria and sub-criteria in enhancing the risk management of construction projects using BIM capabilities and technical, knowledge management, financial management, time potential, sustainability, Health and Safety, operation, and maintenance and based on the evaluations and validation of experts, the final factors and sub-factors are provided in Appendix 1

## 3. Methodology.

This study aimed to identify and prioritize BIM-based strategies for improving construction project performance using a multi-stage approach. Figure 1 outlines the research methodology, starting with defining the research question, identifying keywords, conducting a literature review, and categorizing strategies and sub-strategies. The findings were refined with feedback from industry experts and academics, and the final strategy was prioritized using the Analytical Hierarchy Process (AHP) based on their likelihood and impact, with sensitivity analysis ensuring robust results. Expert involvement ensures that the strategies are comprehensive and aligned with industry needs.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



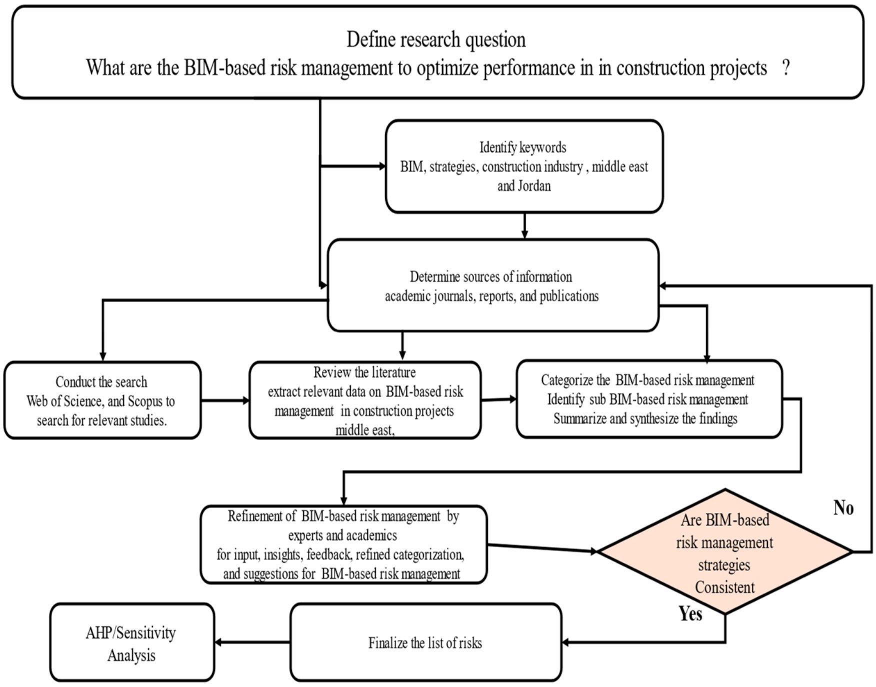


**Figure 1.** The research methodology's sequencing steps.

*3.1 Analytic hierarchy process (AHP)*

This study utilized the AHP method for multi-criteria decision-making, organizing BIM strategies and sub-strategies into a hierarchical framework for prioritization. The hierarchy is designed to highlight the most critical BIM strategies at the top, focusing on their outcomes from a managerial viewpoint. This structure assigns considerable weight to the overall strategic outcomes, ensuring that the most critical BIM strategies are identified. The AHP process follows several key steps, as described by Saaty [63]:

*Step 1. Problem Definition*: The first step involves clearly defining the problem or decision by identifying the objectives, criteria, and alternatives relevant to the decision-making process.

*Step 2. Construct a Hierarchical Structure:* Next, a hierarchical model is created (see Figure 2), organizing the objectives, criteria, and alternatives in a tree-like structure, with the primary objective at the top and alternatives at the bottom.

*Step 3. Pairwise Comparisons:* This step involves comparing strategies and sub-strategies to determine their normalized priority weights. The pairwise comparison includes several sub-steps:

*Creates pairwise comparison matrices for BIM-strategies and their sub-strategies.*

Pairwise Comparison matrices are created for strategies and sub-strategies, with certain elements reflecting reciprocity. This study uses Saaty's [63] nine-point scale (shown in Table 1) to assess the importance of criteria and sub-criteria in a standardized and unbiased way. During pairwise comparisons, these evaluations are converted into integer values. If element (i) is deemed superior to element (j), the corresponding row and column in the matrix are assigned this integer. In contrast, the reciprocal is placed in the opposite row and column. When two elements are judged equal, both positions receive a value of 1, ensuring the matrix follows the reciprocity principle as shown in Equation (1).

$$c_{ij} = \frac{1}{c_{ji}}\,; i, j = 1,2, \ldots n) \qquad (1)$$

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



**Table 1.** Saaty's 1-9 scale for Pairwise comparison based on Saaty (1987).

| Weight Intensity | Definition | Explanation |
|---|---|---|
| 1 | Equally important | Two elements contribute equally to the objective. |
| 3 | Moderately important | Experience and judgment slightly favor one over another. |
| 5 | Strongly important | Experience and judgment strongly favor one over another. |
| 7 | Very Strongly important | One element is strongly favored, and its dominance is demonstrated in practice. |
| 9 | Extremely important | The importance of one over another is affirmed in the highest possible order. |
| 2, 4, 6, 8 | Intermediate weights | Used to express intermediate values between the above-defined weights. |

Weight intensity indicates the significance or preference of one element over another in a pairwise comparison. This scale is a crucial aspect of the AHP method, allowing decision-makers to perform consistent and objective comparisons between elements. It provides a numerical basis for assessing various criteria or alternatives' relative importance or preference in decision-making.

Additionally, constructing aggregate comparison matrices involves combining the evaluations from experts who have provided pairwise comparisons for different strategies and sub-strategies. As Vargas [64] described, the geometric mean method is applied to derive the combined judgment for each element within the matrices. This results in an aggregated comparison matrix, A = [aij], corresponding to a specific attribute. Each element (aij) reflects the geometric mean of the judgments from N decision-makers, calculated using equation (2) as detailed below:

$$a_{ij} = \left( \prod_{i=1}^{N} c_{ij} \right)^{1/N} \quad (2)$$

*Derive and calculate the relative weights of each strategy and sub-strategy.*

Deriving and calculating the relative weights for each strategy and sub-strategy involves generating a normalized matrix (N) corresponding to the comparison matrix (A). The construction of this normalized matrix follows the equations provided in (3) below:

$$N = [n_i], where\ n_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (3)$$

Next, all strategies' relative priorities or weights are determined by averaging the elements in each row of the normalized matrix (N), as shown in Equation 4. These priorities form the priority vector W = [wi], a column matrix of dimension n X 1, where each element [wi] represents an eigenvalue and indicates the weight assigned to a particular factor.

$$w_i = \frac{\sum_{j=1}^{n} n_{ij}}{n} \quad (4)$$

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



To ensure the validity of the outcomes, the consistency of each comparison matrix is evaluated using the Consistency Ratio (CR). A CR of 0.10 or less indicates acceptable consistency within the comparison matrix A, supporting the ranking results [63]. If the CR exceeds 0.10, the rankings cannot be validated, and the decision maker must reassess the evaluation process. A matrix A is deemed consistent if AW=nW. According to Saaty [63], the largest eigenvalue (λmax) should be greater than or equal to (n), with consistency increasing as (λmax) approaches (n). The calculation of (λmax) is performed using equation (5) as follows:

$$AW = \lambda_{max} W \quad (5)$$

The following formula (Equation 6) is used to calculate the consistency ratio (CR):

$$CR = \frac{CI}{RI} \quad (6)$$

The CI is the consistency index calculated based on following formula (Equation 7):

$$CI = \frac{\lambda_{max} - 1}{n - 1} \quad (7)$$

The Random Index (RI) is used alongside Saaty's Consistency Ratio (CR) to evaluate the consistency of a comparison matrix. RI provides a benchmark based on the matrix's order (the number of elements compared) and helps determine if the CR is within an acceptable range. Saaty (1980) outlined recommended CR values in relation to the RI, as shown in Table 2.

Table 2. Random index (RI) and recommended consistency ratio (CR) values (Saaty, 1970).

| | n | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| **Random Index** | RI | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |
| **Recommended CR value** | | <0.05 | <0.08 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 | <0.10 |

The random index assesses the consistency of pairwise comparisons, a key element of the AHP method. A lower consistency ratio (CR) reflects greater consistency and strengthens the reliability of AHP results. As the number of criteria increases, the random index rises, making consistent comparisons more difficult. However, the recommended CR values remain relatively low (<0.10), suggesting consistent comparisons are achievable even with more significant criteria sets. The evaluators' pairwise comparison scores were analyzed using the geometric mean for accuracy.

*Calculating Global Weights*

Local weights, obtained from pairwise comparisons, reflect the importance of a sub-strategy relative to others within the same category. On the other hand, global weights represent the overall significance of a sub-strategy within the entire decision hierarchy. The global weight is computed using the following formula:

*Global weight of a sub-strategy* = *Local weight of the sub-strategy* × *Local weight of the corresponding primary strategy*

*Step 4. Sensitivity Analysis*: This process assesses the robustness of the decision by analyzing how variations in weights or input values affect the final outcome.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



### *3.2 Data collection*

The AHP methodology was guided by the insights of ten experts from construction companies. The study examined risk-management-savvy firms with over ten years of experience. The researchers asked ten construction professionals and one academic to complete a questionnaire with key strategies and BIM sub-strategies from a literature review. Participants included management, assistant general managers, project managers, quality and development specialists, and a construction industry professor and experts. To avoid inconsistencies, the study only included ten respondents [63, 65]. Previous research has successfully used AHP with a few experts [66]. All chosen experts were from Jordanian construction firms. These experts and an academic specialist were interviewed about Jordanian risk management main and sub-BIM strategies.

A hierarchical model has been developed to manage risks associated with BIM strategies, featuring a three-level conceptual structure as in Figure 2. The model's goal is to manage BIM strategies (level 1) by utilizing the main BIM strategy categories for decision-making (level 2) and further breaking them down into sub-strategies (level 3). These seven categories were derived from literature reviews and insights from industry experts. Data was collected via a questionnaire in which participants evaluated eight BIM strategy categories and 37 sub-strategies, making pairwise comparisons at each hierarchical level using Saaty's 1-9 scale. A composite vector with normalized weights was created based on the relationships between the levels. Consistency was verified through the Consistency Index (CI) and Consistency Ratio (CR) for BIM strategies and sub-strategies, ensuring reliable expert data.

## 4. Results

The researchers developed a conceptual hierarchy model for BIM strategies and sub-strategies, as shown in Figure 2, by reviewing existing knowledge and consulting construction industry experts. After aligning with experts, the model was validated against prior theoretical literature. This framework categorizes BIM strategies at a high level, with each category containing sub-strategies addressing specific concerns. It provides a clear breakdown of key BIM strategies for optimizing performance and mitigating risks in construction, supported by expert input to ensure it reflects the industry's most critical priorities.

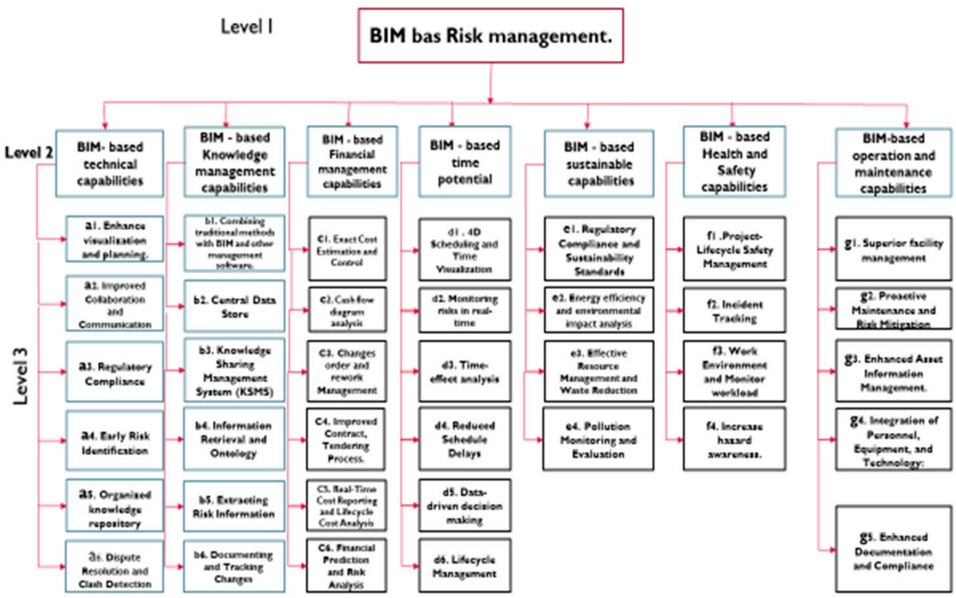


Figure 2. Hierarchal model of BIM strategies.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



*4.1 Results of AHP- Pairwise comparison*

Table 3 shows BIM strategy criterion-to-criterion pairwise comparisons, while Table 4 shows the normalized matrix at the same level. Table 5 shows the local weights (LW) and rankings (LR) of the seven BIM strategies from the pairwise comparison matrix and AHP analysis, as shown in Figure 3. Based on its eigenvector values at level 1, the financial criterion (BIM_3) ranks first with a weight of 0.4099. This suggests that financial factors most influence BIM strategy decisions. Sustainability (BIM_5) ranks second with 0.1734, followed by time (BIM_4) at 0.1433.

Knowledge (BIM_2) ranks fourth with 0.1387 weight, indicating moderate importance. Health and safety capabilities (BIM_6) rank fifth with 0.0631, less critical than financial, sustainability, and time factors. Technology (BIM_1) strategies rank sixth with 0.0388, while operation and maintenance capabilities (BIM_7) rank last with 0.0328.

The weights and ranks indicate that financial, sustainability, and time factors dominate the formulation of a BIM strategy, as supported by Siegrist and Árvai [4]. At the same time, technical capabilities, health safety, and operational maintenance are less critical. In the BIM decision-making process, this hierarchy prioritizes cost, environmental sustainability, and project schedules over technical and operational factors. Finally, Table 6 shows the randomness index (RI) and the recommended consistency ratio (CR), checked against the value of the most important eigenvector in Table 2.

Table 3. Criterion to criterion pairwise comparison matrix for BIM strategies.

| | | BIM_1 | BIM_2 | BIM_3 | BIM_4 | BIM_5 | BIM_6 | BIM_7 |
|---|---|---|---|---|---|---|---|---|
| **Main Strategies (BIM Based)** | BIM_1. Technical | 1 | 1/4 | 1/8 | 1/3 | 1/6 | 1 | 1 |
| | BIM_2. Knowledge | 4 | 1 | 1/4 | 2 | 1 | 2 | 3 |
| | BIM_3. Financial | 8 | 4 | 1 | 5 | 2 | 9 | 9 |
| | BIM_4. Time | 3 | 1/2 | 1/5 | 1 | 2 | 3 | 5 |
| | BIM_5. Sustainable | 6 | 1 | 1/2 | 1/2 | 1 | 5 | 5 |
| | BIM_6. Health and Safety capabilities | 1 | 1/2 | 1/9 | 1/3 | 1/5 | 1 | 5 |
| | BIM7. Operation and maintenance capabilities | 1 | 1/3 | 1/9 | 1/5 | 1/5 | 1/5 | 1 |

Table 4. Matrix Normalization for BIM strategies (Criterion-to-Criterion).

| | BIM_1 | BIM_2 | BIM_3 | BIM_4 | BIM_5 | BIM_6 | BIM_7 |
|---|---|---|---|---|---|---|---|
| BIM_1 | 0.04 | 0.03 | 0.05 | 0.04 | 0.03 | 0.05 | 0.03 |
| BIM_2 | 0.17 | 0.13 | 0.11 | 0.21 | 0.15 | 0.09 | 0.10 |
| BIM_3 | 0.33 | 0.53 | 0.44 | 0.53 | 0.30 | 0.42 | 0.31 |
| BIM_4 | 0.13 | 0.07 | 0.09 | 0.11 | 0.30 | 0.14 | 0.17 |
| BIM_5 | 0.25 | 0.13 | 0.22 | 0.05 | 0.15 | 0.24 | 0.17 |
| BIM_6 | 0.04 | 0.07 | 0.05 | 0.04 | 0.03 | 0.05 | 0.17 |
| BIM_7 | 0.04 | 0.04 | 0.05 | 0.02 | 0.03 | 0.01 | 0.03 |

Table 5. Eigenvector and largest eigenvector value.

| Criterion | W | Rank | AW | λ | CI | RI | CR |
|---|---|---|---|---|---|---|---|
| **BIM_1** | 0.0388 | 6 | 0.2972925 | 7.6602688 | 0.0990636 | 1.32 | 0.0750481 |
| **BIM_2** | 0.1387 | 4 | 1.0810368 | 7.7936061 | | | |
| **BIM_3** | 0.4099 | 1 | 3.2016413 | 7.810613 | | | |

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024
doi:10.20944/preprints202410.1783.v1



| | | | | |
|---|---|---|---|---|
| **BIM_4** | 0.1433 | 3 | 1.1111247 | 7.7526839 |
| **BIM_5** | 0.1734 | 2 | 1.3010401 | 7.5052778 |
| **BIM_6** | 0.0631 | 5 | 0.4633211 | 7.3443781 |
| **BIM_7** | 0.0328 | 7 | 0.2393591 | 7.2938417 |
| | | | | 7.5943813 |

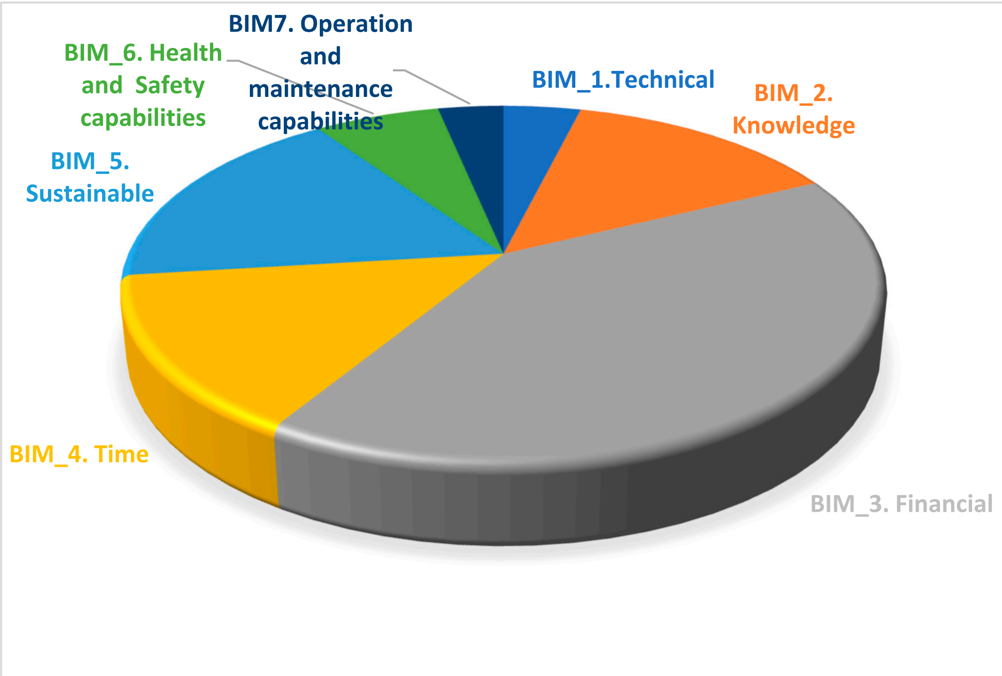


Figure 3. Eigenvector Values of BIM strategies.

A pairwise comparison matrix was used to determine the local weights (LW) and local rankings (LR) of the BIM sub-strategies using the same AHP methodology. Table 6 shows the sub-strategy's local weights and rankings from the AHP analysis.

The local weights of each BIM sub-strategy were multiplied by their primary strategy's local weights to calculate global weights (GW) and rankings. Table 6 shows these results. Figure 4 ranks the BIM sub-strategies with the highest global weights and cumulative impact to show the model's most important.

The BIM strategies and sub-strategies analysis shows Local Weights (LW) and Global Weights (GW) for different criteria, highlighting construction industry risk management and performance optimization priorities. Regulatory Compliance (a3) has the highest Local Weight (LW = 0.4453, ranked 1st) and Global Weight (GW = 0.0173, ranked 18th) among BIM-based technical capabilities, indicating its importance. Enhance Visualization and Planning (a1) and Dispute Resolution and Clash Detection (a6), ranked 36th and 35th, respectively, have lower global impacts with GW values of 0.0016 and 0.0018, making them less critical to BIM technical strategy.

In BIM-based knowledge management capabilities, Knowledge Sharing Management System (KSMS) (b3) is highly significant, with the highest LW (0.4436, ranked 1st) and GW (0.0615, ranked 6th). This sub-strategy emphasizes the importance of information dissemination in enhancing BIM performance [11,12,24]. Other sub-strategies like Extracting Risk Information (b5) (LW = 0.1779, ranked 2nd; GW = 0.0247, ranked 10th) and Cen-

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



tral Data Store (b2) (LW = 0.1482, ranked 3rd; GW = 0.0206, ranked 14th) further underscore the importance of managing knowledge and information within construction projects.

For BIM-based financial management capabilities, Changes Order and Rework Management (c3) dominates, holding the top local weight (LW = 0.4396, ranked 1st) and global weight (GW = 0.1802, ranked 1st overall), signifying its paramount importance in minimizing financial risks and ensuring project stability. Real-Time Cost Reporting and Lifecycle Cost Analysis (c5) follows with a significant GW (0.0720, ranked 3rd overall), underscoring the importance of real-time financial monitoring in BIM [20,39, 40].

In the BIM-based time potential category, Time-effect Analysis (d3) takes the lead with a LW of 0.4514 (ranked 1st) and a global weight of 0.0647 (ranked 4th), highlighting the criticality of time management and its effect on project outcomes [3,35]. Similarly, Monitoring Risks in Real-Time (d2) (GW = 0.0214, ranked 13th) and Data-driven Decision Making (d5) (GW = 0.0246, ranked 11th) play key roles in optimizing project timelines.

When focusing on BIM-based sustainable capabilities, Effective Resource Management and Waste Reduction (e3) emerges as the most influential sub-strategy with the highest LW (0.6068, ranked 1st) and GW (0.1052, ranked 2nd overall), reflecting the industry's increasing prioritization of sustainability and resource efficiency. Energy Efficiency and Environmental Impact Analysis (e2) follows closely (GW = 0.0360, ranked 9th), showing its critical contribution to sustainable construction practices which is supported by Ref. [9, 27,58].

The BIM-based health and safety capabilities category highlights Work Environment and Monitor Workload (f3) as the leading sub-strategy with the highest LW (0.6090, ranked 1st) and GW (0.0384, ranked 8th), emphasized by Musarat et al. [27] the importance of maintaining safety standards and ensuring an optimal working environment. Incident Tracking (f2) and Increased Hazard Awareness (f4) also contribute to this category, although they rank lower globally (21st and 23rd, respectively).

Finally, in BIM-based operation and maintenance capabilities, Enhanced Asset Information Management (g3) leads with a LW of 0.4678 (ranked 1st) and a GW of 0.0154 (ranked 20th), indicating its critical role in operational efficiency and maintenance management which is supported by [19,54].

The consistency check, conducted using the Consistency Index (CI), Random Index (RI), and Consistency Ratio (CR), reveals reliable and valid pairwise comparison results. The CR values across all categories are well within the acceptable threshold of CR < 0.10, with values ranging from 0.02 to 0.07, ensuring consistency in the expert judgments. This consistency indicates that the hierarchical model's comparisons and weight assignments are coherent and logically aligned [66]. For instance, the BIM-based sustainable capabilities category shows a CR of 0.03, affirming that the judgments related to sustainability criteria are robust and consistent. Similarly, other categories like health and safety capabilities and knowledge management capabilities also demonstrate low CR values of 0.03 and 0.06, respectively, further strengthening the model's reliability.

Table 6. Final ranking of BIM Strategies and sub strategies.

| | Local (LW) and Global Weights (GL) | | | | | Consistency Checks | | |
|---|---|---|---|---|---|---|---|---|
| **Main Criteria** | **Index**<br>**Sub Criteria** | **LW** | **Rank (LW)** | **GW** | **Rank (GW)** | **CI** | **RI** | **CR** |
| **BIM- based technical** | a1 | 0.0407 | 6 | 0.0016 | 36 | 0.08 | 1.24 | 0.06 |
| | a2 | 0.1499 | 3 | 0.0058 | 29 | | | |
| | a3 | 0.4453 | 1 | 0.0173 | 18 | | | |
| | a4 | 0.1417 | 4 | 0.0055 | 31 | | | |

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | a5 | 0.1764 | 2 | 0.0068 | 24 | | | |
| | a6 | 0.0461 | 5 | 0.0018 | 35 | | | |
| | b1 | 0.0409 | 6 | 0.0057 | 30 | | | |
| **BIM - based Knowledge management capabilities** | b2 | 0.1482 | 3 | 0.0206 | 14 | | | |
| | b3 | 0.4436 | 1 | 0.0615 | 6 | 0.08 | 1.24 | 0.06 |
| | b4 | 0.1427 | 4 | 0.0198 | 16 | | | |
| | b5 | 0.1779 | 2 | 0.0247 | 10 | | | |
| | b6 | 0.0466 | 5 | 0.0065 | 26 | | | |
| | c1 | 0.0407 | 6 | 0.0167 | 19 | | | |
| **BIM - based Financial management capabilities** | c2 | 0.1570 | 3 | 0.0644 | 5 | | | |
| | c3 | 0.4396 | 1 | 0.1802 | 1 | | | |
| | c4 | 0.1412 | 4 | 0.0579 | 7 | 0.08 | 1.24 | 0.06 |
| | c5 | 0.1757 | 2 | 0.0720 | 3 | | | |
| | c6 | 0.0458 | 5 | 0.0188 | 17 | | | |
| | d1 | 0.0409 | 6 | 0.0059 | 27 | | | |
| | d2 | 0.1496 | 3 | 0.0214 | 13 | | | |
| **BIM - based time potential** | d3 | 0.4514 | 1 | 0.0647 | 4 | 0.07 | 1.24 | 0.06 |
| | d4 | 0.1401 | 4 | 0.0201 | 15 | | | |
| | d5 | 0.1715 | 2 | 0.0246 | 11 | | | |
| | d6 | 0.0465 | 5 | 0.0067 | 25 | | | |
| **BIM - based sustainable capabilities** | e1 | 0.0563 | 4 | 0.0098 | 22 | | | |
| | e2 | 0.2077 | 2 | 0.0360 | 9 | 0.03 | 0.90 | 0.03 |
| | e3 | 0.6068 | 1 | 0.1052 | 2 | | | |
| | e4 | 0.1293 | 3 | 0.0224 | 12 | | | |
| **BIM - based Health and Safety capabilities** | f1 | 0.0564 | 4 | 0.0036 | 34 | | | |
| | f2 | 0.2023 | 2 | 0.0128 | 21 | 0.02 | 0.90 | 0.03 |
| | f3 | 0.6090 | 1 | 0.0384 | 8 | | | |
| | f4 | 0.1323 | 3 | 0.0083 | 23 | | | |
| | g1 | 0.0417 | 5 | 0.0014 | 37 | | | |
| **BIM-based operation and maintenance capabilities** | g2 | 0.1658 | 3 | 0.0054 | 32 | | | |
| | g3 | 0.4678 | 1 | 0.0154 | 20 | 0.08 | 1.12 | 0.07 |
| | g4 | 0.1471 | 4 | 0.0048 | 33 | | | |
| | g5 | 0.1776 | 2 | 0.0058 | 28 | | | |

Table 7 outlines the global weights (GW), rankings of various BIM sub-strategies, and their cumulative weights. The top-ranked sub-strategy, "Changes order and rework Man-

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



agement" (c3), has the highest global weight (GW) of 0.1802, which significantly contributes to the overall strategy with a cumulative weight of 0.1802. This is followed by "Effective Resource Management and Waste Reduction" (e3), ranked second, with a GW of 0.1052 and a cumulative weight of 0.2854, showing its considerable impact on BIM strategies. "Real-Time Cost Reporting and Lifecycle Cost Analysis" (c5) ranks third, with a GW of 0.0720 and a cumulative weight of 0.3574.

The next group of sub-strategies includes "Time-effect analysis" (d3) and "Cash flow diagram analysis" (c2), with global weights of 0.0647 and 0.0644, respectively, both contributing notably to the cumulative weight, reaching 0.4864 by the fifth sub-strategy. These top five sub-strategies collectively account for almost half (48.64%) of the overall BIM strategy, highlighting their importance in the prioritization process.

As the ranking continues, sub-strategies such as "Knowledge Sharing Management System" (b3), "Improved Contract, Tendering Process" (c4), and "Work Environment and Monitor workload" (f3) play key roles, with global weights ranging from 0.0615 to 0.0384. By the time these sub-strategies are considered, the cumulative weight reaches 0.6443, indicating that more than two-thirds of the overall BIM strategies are covered by the top eight sub-strategies.

The subsequent sub-strategies, including "Energy efficiency and environmental impact analysis" (e2), "Extracting Risk Information" (b5), and "Data-driven decision making" (d5), continue to build up the cumulative weight, which reaches 0.7734 by the 13th sub-strategy, "Monitoring risks in real-time" (d2).

Lower-ranked sub-strategies, such as "Incident Tracking" (f2), "Regulatory Compliance and Sustainability Standards" (e1), and "Increase hazard awareness" (f4), contribute less individually to the overall strategy, with global weights below 0.0130. However, their collective impact still pushes the cumulative weight close to full coverage, reaching 0.9528 after 26 sub-strategies.

Finally, the lowest-ranked sub-strategies, including "Dispute Resolution and Clash Detection" (a6) and "Superior facility management" (g1), have minimal individual global weights, contributing marginally to the overall strategy. Figure 4 highlights the BIM sub-strategies global weight (GW) and cumulative weight in increasing order.

Table 7. BIM sub-strategies Global weights (GW) and rankings with their cumulative weights.

| Index- Sub Criteria | GW | Rank (GW) | Cumulative Weight |
|---|---|---|---|
| **c3** | 0.1802 | 1 | 0.1802 |
| **e3** | 0.1052 | 2 | 0.2854 |
| **c5** | 0.0720 | 3 | 0.3574 |
| **d3** | 0.0647 | 4 | 0.4221 |
| **c2** | 0.0644 | 5 | 0.4864 |
| **b3** | 0.0615 | 6 | 0.5480 |
| **c4** | 0.0579 | 7 | 0.6059 |
| **f3** | 0.0384 | 8 | 0.6443 |
| **e2** | 0.0360 | 9 | 0.6803 |
| **b5** | 0.0247 | 10 | 0.7050 |
| **d5** | 0.0246 | 11 | 0.7296 |
| **e4** | 0.0224 | 12 | 0.7520 |
| **d2** | 0.0214 | 13 | 0.7734 |
| **b2** | 0.0206 | 14 | 0.7940 |

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



| | | | |
|---|---|---|---|
| **d4** | 0.0201 | 15 | 0.8140 |
| **b4** | 0.0198 | 16 | 0.8338 |
| **c6** | 0.0188 | 17 | 0.8526 |
| **a3** | 0.0173 | 18 | 0.8699 |
| **c1** | 0.0167 | 19 | 0.8866 |
| **g3** | 0.0154 | 20 | 0.9019 |
| **f2** | 0.0128 | 21 | 0.9147 |
| **e1** | 0.0098 | 22 | 0.9244 |
| **f4** | 0.0083 | 23 | 0.9328 |
| **a5** | 0.0068 | 24 | 0.9396 |
| **d6** | 0.0067 | 25 | 0.9463 |
| **b6** | 0.0065 | 26 | 0.9528 |
| **d1** | 0.0059 | 27 | 0.9586 |
| **g5** | 0.0058 | 28 | 0.9644 |
| **a2** | 0.0058 | 29 | 0.9703 |
| **b1** | 0.0057 | 30 | 0.9759 |
| **a4** | 0.0055 | 31 | 0.9814 |
| **g2** | 0.0054 | 32 | 0.9869 |
| **g4** | 0.0048 | 33 | 0.9917 |
| **f1** | 0.0036 | 34 | 0.9953 |
| **a6** | 0.0018 | 35 | 0.9971 |
| **a1** | 0.0016 | 36 | 0.9986 |
| **g1** | 0.0014 | 37 | 1.0000 |

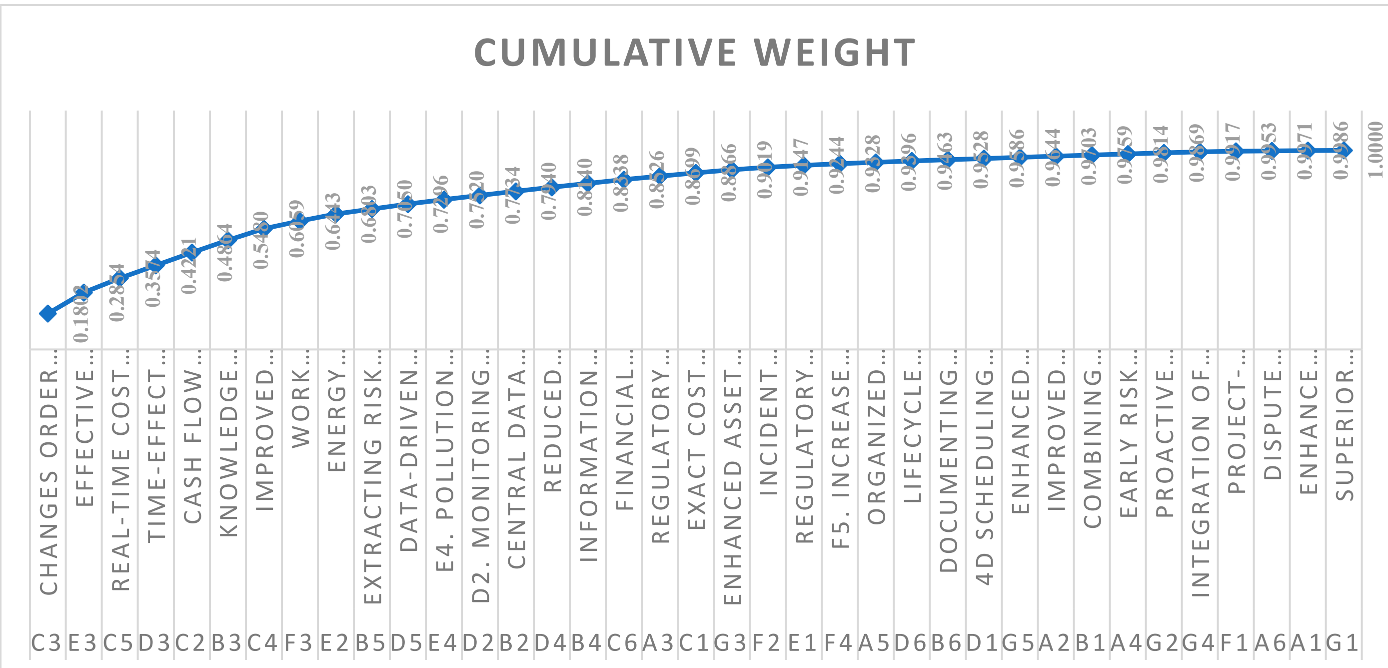


Fig. 4. BIM sub-strategies global weight (GW) and cumulative weight in increasing order.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



The organized ranking and aggregate weights of BIM sub-strategies establish a definitive framework for prioritizing initiatives in BIM implementation. Organizations can significantly refine their BIM strategies by concentrating on critical domains such as order management and resource optimization, resulting in enhanced project outcomes and efficiencies within the construction sector [22].

*4.2. Sensitivity analysis*

The sensitivity analysis conducted in this study provides verification of the stability of rankings and the impact of variations in the weights of leading BIM strategies on the rankings of sub-strategies. This type of analysis is essential for assessing the reliability of the proposed framework, allowing researchers to examine how variations in the weights of primary BIM strategies influence the rankings of the sub-strategies, a method validated by previous studies such as Munny et al. [67].

This study considers 7 main BIM strategies. Among the 7 main strategies, the Financial (BIM_3) have the highest priority as the most critical strategy that influence optimizing performance in the construction industry. Hence, a slight variation in the weight of financial strategy may significantly influence other BIM strategies. In this context, this study changed the weights of the main BIM strategies in proportion to conducting sensitivity analysis. Hence, the Demand risks' weight varies from 0.4099 to (BIM_3.*0.9=0.3689), (BIM_3.*0.8=0.3279,(BIM_3.*0.7=0.2869), (BIM_3.*0.6=0.2459), (BIM_3.*0.5=0.2050), (BIM_3.*0.4=0.1640), (BIM_3.*0.3=0.1230) , (BIM_3.*0.2=0.0820), and (BIM_3.*0.10.=0410). The study conducted a sensitivity analysis by altering the proportions of the weights of the primary BIM strategies. The sensitivity analysis presented in Table 8 explores how changes in the weight of the financial criterion (BIM_3) influence the global weights and rankings of different BIM criteria. This analysis reveals how various criteria adjust their importance relative to each other as the weight of the financial criterion decreases in incremental steps (from 90% to 10% of its original value). Consequently, the weight of financial strategy fluctuated from 0.4099 to 0.041.

As the financial weight is progressively reduced, the analysis reveals shifting importance among the other criteria, the Incremental Changes in the other criteria indicated that BIM_1 (Technical) consistently maintains a low rank (6th place) throughout most weight reductions but moves up to 5th position when the financial weight is reduced to 10% of its original value, reaching a local weight of 0.1003. This indicates that while the technical criterion has less influence under normal circumstances, it becomes relatively more significant when financial considerations are diminished.

BIM_2 (Knowledge) shows steady performance, retaining its 4th place ranking in most scenarios. However, when the financial weight is drastically reduced (to 30% or lower), it advances to 3rd place, highlighting its increasing relevance when the financial factor becomes less dominant.

BIM_3 (Financial), the most dominant criterion in the base case, experiences a significant drop in importance as its weight is reduced. By the time the financial weight is cut to 50%, it still holds the first position but loses this ranking as the weight is further reduced to 40%, where Sustainable (BIM_5) takes over. Once the financial weight reaches 20%, the Financial criterion plummets to 7th place with a weight of just 0.0410, indicating that its dominance heavily depends on its original weight allocation.

BIM_4 (Time) displays consistency, maintaining its 3rd position under most weight scenarios. When the financial weight is reduced to 30% or less, Time rises to 2nd place, illustrating that the criterion becomes more influential when financial concerns are minimized.

BIM_5 (Sustainable) shows a steady increase in importance as the financial weight is reduced. It climbs to 1st place when the financial weight drops to 40% or lower, indicating the growing priority of sustainability considerations when financial constraints are relaxed. Its final weight at 10% of the financial criterion is 0.2348, the highest among all criteria at that point.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



BIM_6 (Health and Safety) remains relatively stable in 5th position but eventually rises to 4th place when the financial weight drops to 20%. This reflects that health and safety concerns become more prominent in lower financial weight scenarios, though they remain moderately influential overall.

Finally, BIM_7 (Operation and Maintenance) consistently holds the lowest rank (7th place) throughout most sensitivity analyses. However, it rises to 6th place when the financial weight is reduced to 10%, suggesting that while it generally has a lower impact, its importance increases slightly in less financially-driven scenarios.

The key observation from sensitivity analysis offers a clear view of how various BIM criteria shift in relevance as financial considerations are adjusted. For instance, the Financial criteria of construction projects is dominant as The Financial criterion (BIM_3) clearly dominates under normal conditions but rapidly loses its influence as its weight is decreased. This underscores the critical role financial considerations play in BIM decision-making, though this influence can shift significantly when financial factors are deprioritized. Furthermore, Sustainability Emergence as The Sustainable criterion (BIM_5) shows notable growth in importance, eventually surpassing

Financial when the latter is weight decreases to 40% or less. This shift highlights the increasing relevance of sustainability in situations where financial concerns are less central. Moreover, Consistency of Time and Knowledge as Both Time (BIM_4) and Knowledge (BIM_2) show stability throughout the analysis, maintaining similar rankings across different financial weight scenarios. This indicates that these criteria maintain their importance regardless of financial shifts, reflecting their intrinsic value in BIM strategies. Finally, Technical, Health, and Safety Growth These two criteria (BIM_1 and BIM_6) show modest but noticeable improvements in their rankings as the financial weight decreases, reflecting their growing importance in less financially driven decision-making contexts. Figure 5 illustrates the BIM criteria changes with the varying weight of the financial criterion (BIM_3).

Table 8. BIM criteria change with the varying weight of the financial criterion (BIM_3)

| | | | Incremental changes | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Criteria** | **Normal Weights** | **Normal Ranks** | **BIM_3.*0.9** | **Rank** | **BIM_3.*0.8** | **Rank** | **BIM_3.*0.7** | **Rank** | **BIM_3.*0.6** | **Rank** | **BIM_3.*0.5** | **Rank** | **BIM_3.*0.4** | **Rank** | **BIM_3.*0.3** | **Rank** | **BIM_3.*0.2** | **Rank** | **BIM_3.*0.1** | **Rank** |
| **BIM_1.Technical** | 0.0388 | 6 | 0.0456 | 6 | 0.0525 | 6 | 0.0593 | 6 | 0.0661 | 6 | 0.0730 | 6 | 0.0798 | 6 | 0.0866 | 6 | 0.0935 | 5 | 0.1003 | 5 |
| **BIM_2. Knowledge** | 0.1387 | 4 | 0.1455 | 4 | 0.1524 | 4 | 0.1592 | 4 | 0.1660 | 4 | 0.1729 | 4 | 0.1797 | 3 | 0.1865 | 3 | 0.1934 | 3 | 0.2002 | 3 |
| **BIM_3. Financial** | 0.4099 | 1 | 0.3689 | 1 | 0.3279 | 1 | 0.2869 | 1 | 0.2459 | 1 | 0.2050 | 2 | 0.1640 | 4 | 0.1230 | 4 | 0.0820 | 7 | 0.0410 | 7 |
| **BIM_4. Time** | 0.1433 | 3 | 0.1502 | 3 | 0.1570 | 3 | 0.1638 | 3 | 0.1706 | 3 | 0.1775 | 3 | 0.1843 | 2 | 0.1911 | 2 | 0.1980 | 2 | 0.2048 | 2 |

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **BIM_5. Sustainable** | 0.1734 | 2 | 0.1802 | 2 | 0.1870 | 2 | 0.1938 | 2 | 0.2007 | 2 | 0.2075 | 1 | 0.2143 | 1 | 0.2212 | 1 | 0.2280 | 1 | 0.2348 | 1 |
| **BIM_6. Health and Safety capabilities** | 0.0631 | 5 | 0.0699 | 5 | 0.0767 | 5 | 0.0836 | 5 | 0.0904 | 5 | 0.0972 | 5 | 0.1041 | 5 | 0.1109 | 5 | 0.1177 | 4 | 0.1246 | 4 |
| **BIM7. Operation and maintenance capabilities** | 0.0328 | 7 | 0.0396 | 7 | 0.0465 | 7 | 0.0533 | 7 | 0.0601 | 7 | 0.0670 | 7 | 0.0738 | 7 | 0.0806 | 7 | 0.0875 | 6 | 0.0943 | 6 |
| | 1.00 | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | | 1 | |

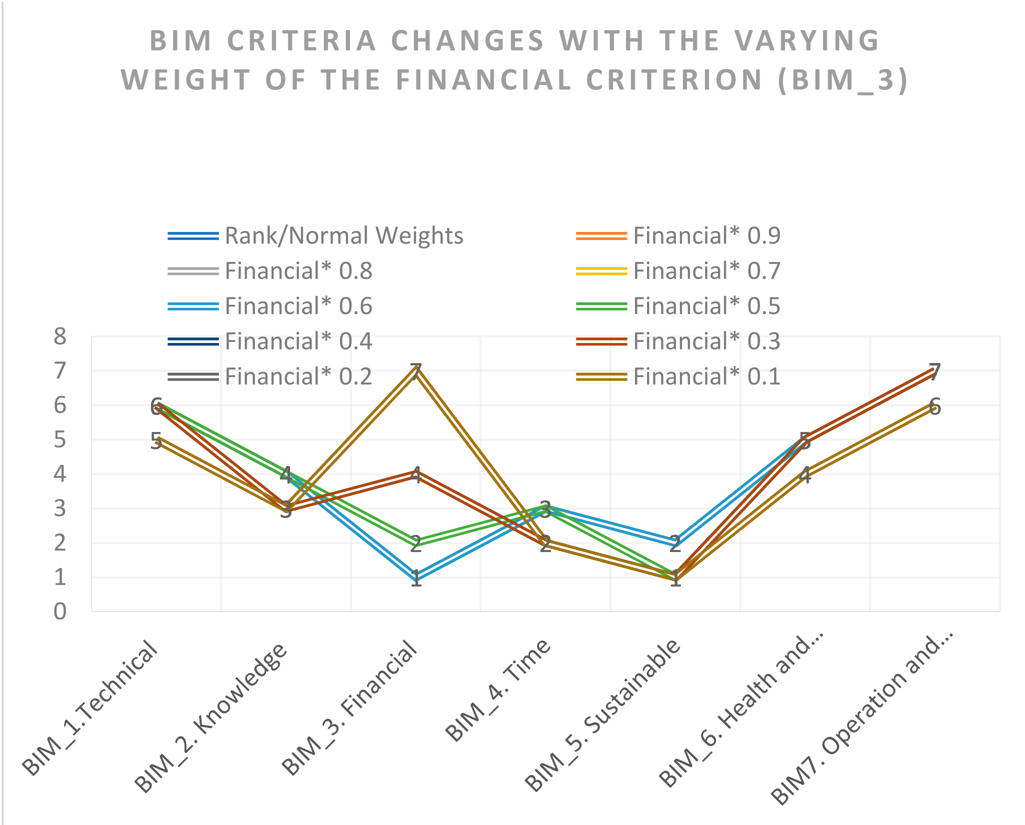


Figure 5. BIM criteria change with the varying weight of the financial criterion (BIM_3)

The analysis of the results from Table 9 reveals several significant shifts in rankings among the BIM sub-criteria as the weight of the Financial criterion (BIM_3) is reduced incrementally. Focusing on the sub-criteria that have experienced the most pronounced changes:

1. Financial Management Sub-Criteria

- Changes Order and Rework Management (c3): Initially ranked 1st in the normal weight scenario, this sub-criterion remains highly prioritized when the Financial weight is 0.9 or 0.8. However, as the Financial weight continues to decrease, its rank

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



gradually drops, particularly after Financial*0.5, where it moves to 4th and then to 16th when Financial is 0.1. This indicates that the importance of this sub-criterion is highly sensitive to financial considerations, and as financial factors become less dominant, the importance of managing change orders and rework declines substantially.

- Real-Time Cost Reporting and Lifecycle Cost Analysis (c5): Ranked 3rd under normal conditions, this sub-criterion remains in the top ranks until the financial weight reaches 0.4, where it starts to drop significantly, eventually falling to 29th when the financial weight is 0.1. This demonstrates that while cost reporting is crucial in financially-driven contexts, its relevance diminishes when financial concerns are deprioritized.
- Improved Contract, Tendering Process (c4): Ranked 7th in the normal scenario, this sub-criterion sees a steady decline in rank as the financial weight decreases, reaching 32nd place when Financial*0.1. Like the others, it indicates a strong dependence on the financial criterion for its importance.

2. Sustainable Capabilities Sub-Criteria

- Energy Efficiency and Environmental Impact Analysis (e2): Starting at 9th place in the normal weight scenario, this sub-criterion improves its rank as the financial weight decreases, moving up to 5th place at Financial*0.1. This suggests that sustainability-related concerns, such as energy efficiency, become increasingly important in scenarios where financial priorities are reduced.
- Effective Resource Management and Waste Reduction (e3): This sub-criterion consistently ranks at the top, remaining in the 1st position throughout the weight reductions. It highlights the critical and stable importance of effective resource management, even when financial concerns are diminished.

3. Time Potential Sub-Criteria

- Time-Effect Analysis (d3): Initially ranked 4th, this sub-criterion remains consistently in the top 3 across the different scenarios, ultimately rising to 2nd place when the financial weight reaches 0.1. This suggests that time-related efficiency is a critical factor, even when financial constraints are reduced.
- Monitoring Risks in Real-Time (d2): Ranked 13th initially, this sub-criterion sees its importance rise as the financial weight decreases, moving up to 10th place when Financial*0.1. Real-time monitoring of risks gains prominence when financial pressures lessen.

4. Health and Safety Sub-Criteria

- Incident Tracking (f2): This sub-criterion starts at 21st place in the normal scenario but gradually improves its rank as the financial weight decreases, moving up to 15th at Financial*0.1. The importance of health and safety management, particularly tracking incidents, becomes more relevant in lower financial weight scenarios.
- Work Environment and Monitor Workload (f3): Ranked 8th in the normal scenario, this sub-criterion climbs to 4th place when Financial*0.1, indicating that as financial concerns become less dominant, the management of work environments and monitoring workloads become more critical.

5. Operation and Maintenance Sub-Criteria

- Enhanced Asset Information Management (g3): Initially ranked 20th, this sub-criterion sees significant improvement in its ranking as the financial weight decreases, eventually moving up to 7th at Financial*0.1. This suggests that asset information management becomes increasingly important as financial priorities are scaled back.
- Proactive Maintenance and Risk Mitigation (g2): Initially ranked 32nd, this sub-criterion improves its rank significantly as financial weight decreases, ultimately reaching 20th place when Financial*0.1, highlighting the growing relevance of proactive maintenance strategies in less financially constrained contexts.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



The General Observations observation from the sensitivity analysis highlights:

- Highly Financial-Dependent Criteria: Sub-criteria like c3 (Changes Order and Rework Management) and c5 (Real-Time Cost Reporting and Lifecycle Cost Analysis) are highly dependent on the financial criterion. As the financial weight decreases, their relevance diminishes dramatically, which is indicative of their strong connection to financial management capabilities.
- Rising Sustainability and Time-Effectiveness: As the financial criterion is deprioritized, sustainability-related sub-criteria such as e2 (Energy Efficiency) and time-related sub-criteria such as d3 (Time-Effect Analysis) gain importance. This shift suggests that when financial concerns are not the primary focus, there is a greater emphasis on sustainable practices and time optimization.

The sensitivity analysis demonstrates the dynamic nature of BIM sub-criteria rankings in response to changes in the weight of financial considerations. The shift towards sustainability, health, safety, and time efficiency as financial concerns diminish underscores the importance of a more balanced approach in BIM strategy prioritization.

Table 9. BIM sub-criteria changes with the varying weight of the financial criterion (BIM_3).

| Main Criteria | Index- sub-criteria | Normal W and Ranks | | | Incremental changes in Global ranks when Financial criterion change | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Local W | Global W | Global Rank | Financial* 0.9 | Financial* 0.8 | Financial* 0.7 | Financial* 0.6 | Financial* 0.5 | Financial* 0.4 | Financial* 0.3 | Financial* 0.2 | Financial* 0.1 |
| **BIM- based technical** | a1 | 0.0409 | 0.0016 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 34 | 34 |
| | a2 | 0.1494 | 0.0058 | 28 | 27 | 26 | 26 | 27 | 25 | 25 | 24 | 22 | 21 |
| | a3 | 0.4409 | 0.0171 | 18 | 17 | 14 | 12 | 11 | 8 | 7 | 7 | 6 | 6 |
| | a4 | 0.1428 | 0.0055 | 31 | 30 | 28 | 28 | 28 | 26 | 26 | 26 | 23 | 22 |
| | a5 | 0.1795 | 0.0070 | 24 | 24 | 24 | 24 | 21 | 20 | 20 | 20 | 17 | 17 |
| | a6 | 0.0464 | 0.0018 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 33 | 33 |
| **BIM - based Knowledge management capabilities** | b1 | 0.0409 | 0.0057 | 30 | 32 | 33 | 33 | 33 | 33 | 32 | 31 | 31 | 28 |
| | b2 | 0.1494 | 0.0207 | 14 | 14 | 15 | 16 | 16 | 16 | 14 | 13 | 13 | 12 |
| | b3 | 0.4409 | 0.0612 | 6 | 5 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 |
| | b4 | 0.1428 | 0.0198 | 16 | 16 | 18 | 18 | 18 | 18 | 17 | 15 | 15 | 14 |
| | b5 | 0.1795 | 0.0249 | 11 | 10 | 10 | 10 | 10 | 11 | 9 | 9 | 9 | 8 |
| | b6 | 0.0464 | 0.0064 | 26 | 28 | 30 | 31 | 31 | 31 | 29 | 29 | 29 | 26 |
| **BIM - based Financial management capabilities** | c1 | 0.0409 | 0.0168 | 19 | 20 | 21 | 21 | 25 | 29 | 33 | 34 | 37 | 37 |
| | c2 | 0.1494 | 0.0613 | 5 | 6 | 6 | 7 | 8 | 9 | 16 | 18 | 24 | 31 |
| | c3 | 0.4409 | 0.1807 | 1 | 1 | 1 | 1 | 2 | 2 | 4 | 5 | 8 | 16 |
| | c4 | 0.1428 | 0.0585 | 7 | 7 | 8 | 8 | 9 | 13 | 18 | 19 | 27 | 32 |
| | c5 | 0.1795 | 0.0736 | 3 | 4 | 5 | 6 | 6 | 7 | 11 | 17 | 21 | 29 |
| | c6 | 0.0464 | 0.0190 | 17 | 19 | 20 | 20 | 23 | 28 | 31 | 33 | 35 | 36 |
| **BIM - based time potential** | d1 | 0.0409 | 0.0059 | 27 | 31 | 32 | 32 | 32 | 32 | 30 | 30 | 30 | 27 |

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | d2 | 0.1494 | 0.0214 | 13 | 13 | 13 | 15 | 15 | 15 | 13 | 11 | 11 | 10 |
| | d3 | 0.4409 | 0.0632 | 4 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 |
| | d4 | 0.1428 | 0.0205 | 15 | 15 | 16 | 17 | 17 | 17 | 15 | 14 | 14 | 13 |
| | d5 | 0.1795 | 0.0257 | 10 | 11 | 11 | 11 | 12 | 12 | 10 | 10 | 10 | 9 |
| | d6 | 0.0464 | 0.0067 | 25 | 26 | 29 | 30 | 30 | 30 | 28 | 28 | 28 | 25 |
| **BIM - based sustainable capabilities** | e1 | 0.0563 | 0.0098 | 22 | 22 | 22 | 23 | 22 | 23 | 24 | 25 | 26 | 24 |
| | e2 | 0.2057 | 0.0357 | 9 | 9 | 9 | 9 | 7 | 6 | 6 | 6 | 5 | 5 |
| | e3 | 0.6076 | 0.1053 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| | e4 | 0.1304 | 0.0226 | 12 | 12 | 12 | 13 | 14 | 14 | 12 | 12 | 12 | 11 |
| **BIM - based Health and Safety capabilities** | f1 | 0.0563 | 0.0036 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 32 | 32 | 30 |
| | f2 | 0.2057 | 0.0130 | 21 | 21 | 19 | 19 | 19 | 19 | 19 | 16 | 16 | 15 |
| | f3 | 0.6076 | 0.0383 | 8 | 8 | 7 | 5 | 5 | 5 | 5 | 4 | 4 | 4 |
| | f4 | 0.1304 | 0.0082 | 23 | 23 | 23 | 22 | 20 | 21 | 21 | 21 | 18 | 19 |
| **BIM-based operation and maintenance capabilities** | g1 | 0.0415 | 0.0014 | 37 | 37 | 37 | 37 | 37 | 37 | 37 | 37 | 36 | 35 |
| | g2 | 0.1678 | 0.0055 | 32 | 29 | 27 | 27 | 26 | 24 | 23 | 23 | 20 | 20 |
| | g3 | 0.4657 | 0.0153 | 20 | 18 | 17 | 14 | 13 | 10 | 8 | 8 | 7 | 7 |
| | g4 | 0.1489 | 0.0049 | 33 | 33 | 31 | 29 | 29 | 27 | 27 | 27 | 25 | 23 |
| | g5 | 0.1761 | 0.0058 | 29 | 25 | 25 | 25 | 24 | 22 | 22 | 22 | 19 | 18 |

The analysis for BIM-based financial management capabilities (BIM_3. Financial) shows a dynamic shift in financial sub-criteria prioritization as financial criterion weighting changes. In particular, the Exact Cost Estimation and Control (c1) sub-criteria have declined in importance. This sub-criterion drops from 19th to 37th as financial weight decreases. This suggests that cost estimation and control are essential when financial constraints are prioritized but less so when they are not. Cash Flow Diagram Analysis (c2) follows a similar pattern. Starting at 5th under normal financial conditions, it steadily falls to 31st. Cash flow management depends heavily on financial factors but becomes less important when sustainability or operational efficiency takes precedence.

Under normal financial conditions, Changes in Order and Rework Management (c3) are the most essential financial prioritization sub-criterion. It falls to 16th place as its financial weight decreases. According to this result, managing changes and rework can significantly reduce costs in financially driven environments. However, as financial concerns fade, other factors take precedence, reducing the focus on this sub-criterion. Improved Contract, Tendering Process (c4) starts at 7th and drops to 32nd as financial weight decreases. This shows that contract and tendering process improvements are more important when financial management is critical but less so when not.

Also falling in rank are Real-Time Cost Reporting and Lifecycle Cost Analysis (c5). This sub-criterion drops from 3rd to 29th as financial weight decreases. According to the findings, financial criteria require real-time cost monitoring and lifecycle cost analysis. When financial concerns become less important, other project management tasks take precedence, reducing the importance of real-time cost management. Financial Prediction and Risk Analysis (c6) starts at 17th and drops to 36th as financial weight decreases. This supports the idea that financial prediction and risk analysis are closely related to financial management and become less relevant as financial constraints are deprioritized.

The analysis shows that financial management sub-criteria depend heavily on the financial criterion. As the financial criterion decreases, sub-criteria like Exact Cost Estimation and Control (c1), Changes Order and Rework Management (c3), and Real-Time Cost

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



Reporting and Lifecycle Cost Analysis (c5) become less important. This suggests that financial management activities are most crucial in financially driven decision-making contexts but less critical when sustainability or operational efficiency are more important. The consistent decline across all financial sub-criteria shows that BIM decision-making is multidimensional and requires balancing financial priorities with other critical issues. The findings suggest that BIM implementation should be flexible, prioritizing financial management capabilities according to project priorities.

The analysis of Regulatory Compliance (a3) shows that it gains importance as financial weight decreases. Financial considerations start at the 18th and rise to the 6th when prioritized. This shows how vital regulatory compliance is in non-financial environments.

Due to compliance requirements' non-negotiability, organizations appear to prioritize regulatory standards over financial criteria as the latter lose weight. Unlike financial management, regulatory compliance is often required and directly affects project legal and operational feasibility. Its steady rise from 18th to 6th place shows its growing importance as other financial factors fade.

This suggests that financial management drives project planning in the early stages, but regulatory compliance takes over as finances fade. This criterion becomes more critical as economic concerns are deprioritized because organizations must comply with regulations to avoid legal penalties, project delays, and other risks.

Regulatory Compliance (a3) is becoming more critical as financial priorities change. In BIM decision-making, regulatory compliance becomes increasingly essential to project success and viability, especially when financial constraints are less important. The steady rise in ranking reflects a shift from financial management to operational and legal considerations.

Finally, Documenting and Tracking Changes (b6) performs consistently across financial weights. It starts at 26 and drops to 31 before returning to 26 as finances ease. This stability suggests that BIM processes must document and track changes regardless of financial priorities. A temporary focus on financially oriented criteria may explain its slight ranking drops. Still, its overall position indicates its foundational importance despite being a secondary priority to cost control and compliance.

Lifecycle Management (d6) starts at rank 25 and fluctuates to 26–30 before returning to 25 across financial weightings. This consistency shows its long-term role in BIM, which is essential but not a priority when economic factors are emphasized. Even without financial considerations, Lifecycle Management remains critical, but minor changes suggest periodic shifts in focus to other criteria.

## 4. Discussion

The study investigates incorporating (BIM) technology into construction project risk management to improve risk detection, assessment, and mitigation. Technical, financial, sustainability, and time management concerns prioritize BIM-based plans using the Analytical Hierarchy Process (AHP). Economic strategy, sustainability, and temporal variables are crucial to BIM-driven risk management. The research shows how BIM improves project results by enabling real-time decision-making, collaboration, cost management, and resource utilization efficiency. The findings of this study are consistent with the current body of literature because they emphasize the significance of financial strategies, particularly those centered on cost reporting and lifecycle analysis, during the first phases of building information modeling (BIM) deployment [68].

Integrating (BIM) in construction risk management has shown significant potential for enhancing project performance. The study's findings validate the significance of BIM-based techniques, especially in addressing financial risks, sustainability issues, and time efficiency in building projects. Financial management has emerged as the paramount aspect, corroborating prior research that underscores the importance of financial methods for project stability and cost control [10,60,68].

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



This study's sensitivity analysis reveals how altering the weights of fundamental BIM strategies, notably financial criteria, impacts sub-strategies ranking and relevance. This approach verifies ranking framework robustness [67]. It also shows how criteria and sub-criteria change when financial considerations change, demonstrating the dynamic nature of BIM strategy prioritizing decision-making [68]. Under normal conditions, the financial strategy (BIM_3) is prioritized most. Therefore, any change in its weight considerably influences the total ranking of BIM strategies. Once the financial weight falls below 40%, BIM_5 (sustainable) becomes the most significant criterion. This trend shows sustainability is becoming more critical in non-financial circumstances [8,9]. BIM_4 (time) and BIM_2 (knowledge) perform similarly across financial weight scenarios, demonstrating their value independent of financial priority, which is supported by [24,35]. The sensitivity analysis shows that financial weight affects specific tactics more than others. BIM_1 (technical) and BIM_6 (health and safety) gain somewhat when financial weight declines. These factors are crucial when financial concerns are decreased, demonstrating that technical and safety issues become more significant in decision-making when cost limitations are lowest.

The sub-strategy analysis shows that financial weight strongly influences change order and rework management, real-time cost reporting, and life cycle cost analysis. These sub-criteria drop sharply when the economic criterion is weighted down, showing diminished relevance in non-financial circumstances. As financial concerns decrease, sustainability-related sub-criteria rise in rank, including energy efficiency, environmental impact assessments, efficient resource management, and waste reduction. Aladaileh et al. [8] assert that reduced financial priorities may make sustainable practices and resource management more important in decision-making.

The sensitivity analysis shows that BIM plan prioritizing should be more balanced, especially when budgetary restrictions are less critical. Financial reasons frequently dominate decision-making, but sustainability, time efficiency, and health and safety gain prominence when financial concerns wane. These data imply that flexible and dynamic BIM deployment improves project performance in varied circumstances.

BIM also improves environmental, health, and safety procedures, which are more important in less financially motivated situations. The study advances BIM as a transformational tool by providing a systematic way to balance building project goals. Thus, future research should improve BIM-based risk management frameworks for broader use. This study shows that BIM plans are dynamic and require a balanced strategy that adjusts to shifting objectives for long-term project success.

## 5. Conclusion.

Experienced Jordanian construction specialists find BIM helpful in minimizing and analyzing risks across the project life cycle. The results are specific to the Jordanian building sector and cannot be generalized. Experts from various populations may potentially have different results. This study should be seen as an experimental study that gives first insights into using BIM to manage construction project risks, which may inform future studies on BIM in diverse contexts.

The researchers' conceptual hierarchical model of BIM strategies and sub-strategies advances our understanding of construction performance and risk. The model organizes BIM strategies by interviewing experts and comparing their replies to earlier studies. This technique emphasizes the responsibilities of different methods and shows how cost, long-term goals, and time management affect decision-making.

The study shows that financial criteria (BIM_3) are the most important, with a weight of 0.4099, meaning they significantly impact how the BIM strategy is made. As we can see, the second and third most important factors are sustainability (BIM_5) and time management (BIM_4). This order of importance shows that the industry focuses on being cost-effective and positively affecting the environment.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



AHP helped the researchers to appreciate the importance of tactics and strategies more thoroughly. Regulatory compliance has become a technological talent, indicating its importance as financial priorities shift. Documenting and monitoring modifications and other sub-strategies perform consistently across financial weights, proving they are crucial to BIM operations even if they are not always prioritized. The link between project elements and economic priorities is complicated in BIM-based financial management. As financial weight reduces, cost predictions, tight management, cash flow analysis, and real-time cost reporting become less critical. This shows they are more relevant in cost-sensitive circumstances. Following regulations becomes increasingly vital when economic concerns decrease, proving its importance to legal and operational success. This shows why firms must be adaptable when utilizing BIM to modify project goals. Financial management is crucial while planning, but compliance and operations become increasingly vital as projects advance. This research shows how difficult BIM decision-making is and how essential financial management, operational, and regulatory demands are for project success. The research enhances construction management, digital technologies, and risk management theory. It shows how digital techniques like (BIM) may improve risk management theories by employing dynamic data instead of static or fragmented information to identify, analyze, and mitigate risks. The findings show that BIM integrates environmental effect assessment and real-time monitoring, promoting sustainability theory in construction and green building practices. Finally, this complete BIM strategy framework emphasizes the importance of cost, environment, and time considerations for building organizations. According to the research, BIM initiatives should balance regulatory compliance and operational efficiency. Thus, organizations may manage current construction complexity while monitoring crucial performance parameters.

For the theoretical Implication, the study supports the idea that data-driven risk mitigation is better in complex environments like construction. Knowledge management using BIM promotes stakeholder knowledge sharing and aligns with knowledge-centric project management philosophies. The results show that BIM can combine environmental effect assessment and real-time monitoring, promoting sustainability theory in construction and green building practices. This study uses the Analytical Hierarchy Process (AHP) in a BIM framework to help project managers prioritize risks and decisions, improving risk prioritization models. It shows BIM's complicated function in enhancing risk management, wise financial decision-making, and construction sustainability, addressing current theories' flaws.

Practical implications are significant for industry professionals, particularly in improving the management, execution, and outcomes of construction projects. Project managers may also guarantee that designs fulfill regulatory standards, eliminating delays and penalties. These practical consequences show that BIM-based risk management may improve cooperation, reduce risk, and make building projects more efficient, cost-effective, and sustainable. Construction businesses that use BIM to improve project results and reduce operational inefficiencies may gain a competitive edge.

**limitations**

The study focuses on BIM-based risk management within the construction industry, particularly in Jordan, which may limit the generalizability of the findings to other contexts. The unique challenges and dynamics of the Jordanian construction industry, including its regulatory, economic, and political environments, may differ from different regions. While the study uses expert input to validate its framework and strategies, the sample size of experts is relatively small (10 participants). This small sample size may not capture the diversity of opinions and experiences within the broader construction sector, limiting the robustness of the findings. The sensitivity analysis also revolves primarily around financial criteria (BIM_3), which, while important, may overshadow other BIM

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



strategies such as sustainability, time, and health and safety. A more comprehensive analysis that includes all BIM strategies equally may reveal different insights. The study does not fully explore integrating emerging technologies such as artificial intelligence, machine learning, or the Internet of Things with BIM to enhance risk management practices. This omission may lead to missing potential avenues for innovation and efficiency in construction management.

Future research should look beyond Jordan to evaluate BIM-based risk management solutions in other cultural, economic, and regulatory contexts. More considerable research with additional building industry professionals from different sectors would give a broader viewpoint and improve dependability. Including specialists from other locations or industries would make the framework more relevant.

Longitudinal studies are needed to assess BIM-based risk management systems' long-term efficacy. Researchers may follow projects over time to discover how BIM adoption affects construction project success across the project life cycle.

A more balanced BIM strategy investigation is needed. Instead of concentrating on finances, future studies should analyze sensitivity assessments on BIM strategies, including sustainability, time management, and health and safety. This would clarify how tactics interact in different project situations.

*Funding.*

This research received no external funding.

*Data Availability Statement.*

The data will be available upon reasonable request.

*Conflicts of Interest*

The authors declare no conflict of interest.

**Appendix 1.**

**Main criteria and Sub-criteria of the BIM bas Risk management.**

| Index | Main criteria | Index | Sub criteria | Descriptions | References |
|---|---|---|---|---|---|
| **A** | **BIM- based technical capabilities** | **a1** | **Enhance visualization and planning.** | BIM's 3D visualization of building projects helps discover design and logistical concerns early on. This visualization prevents expensive mid-construction adjustments and delays. | [3,4, 53] |
| | | **a2** | **Improved Collaboration and Communication** | BIM improves stakeholder cooperation by allowing real-time updates and communicating changes to all team members. Live collaboration reduces errors and misunderstandings. | [47,49] |
| | | **a3** | **Regulatory Compliance** | Automatically checking if project designs comply with standards. This feature reduces the risk of | [59] |

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



| | | | | | |
|---|---|---|---|---|---|
| | | | | compliance-related issues, potential fines, or rework. | |
| | | **a4** | **Early Risk Identification** | Fast 3D project information modeling. Accurate forecasting and visualization of project development, management, and maintenance improves risk communication and mitigation. | [54,55] |
| | | **a5** | **Organized knowledge repository** | BIM organizes, stores, and shares risk information from project participants, capturing and using fragmented data to address risk concerns quickly. | [1,4,6] |
| | | **a6** | **Dispute Resolution and Clash Detection** | Early clash detection allows for solving problems in the virtual environment ( (e.g., structural, mechanical, electrical), reducing the risk of rework and delays. | [32,33] |
| B | **BIM - based Knowledge management capabilities** | **b1** | **Combining traditional methods with BIM and other management software.** | Utilizing databases, risk management tools, and project management software enhances project development risk detection, analysis, and information management, facilitating end-to-end risk management through data transit across systems. | [11,12] |
| | | **b2** | **Central Data Store** | BIM helps all stakeholders have access to the latest information by consolidating data. Effective risk management requires centralized risk detection, analysis, and mitigation throughout a project. | [24,61] |
| | | **b3** | **Knowledge Sharing Management System (KSMS)** | Project managers and engineers may exchange BIM expertise on KSMSs. This technology may record project information for future risk mitigation. | [53,54] |

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



| | | | | | |
|---|---|---|---|---|---|
| | | **b4** | **Information Retrieval and Ontology** | BIM technology utilizes ontology and semantic web technologies to describe construction risk information semantically. This improves safety management risk knowledge and communication. | {16,17} |
| | | **b5** | **Extracting Risk Information** | BIM manages 3D/4D information models in a virtual environment before construction to improve risk information extraction. It simplifies risk identification and communication, improving risk management. | [15, 16,17] |
| | | **b6** | **Documenting and Tracking Changes** | BIM excels in recording and tracking project changes. For risk management, this ability helps project teams track changes, understand their implications, and manage their risks. | [18] |
| **C** | **BIM - based Financial management capabilities** | **c1** | **Exact Cost Estimation and Control** | 3D/D5 BIM models improve cost predictions, reduce budget overruns, and enhance project control through detailed visualizations and accurate calculations, enhancing financial understanding of design and construction decisions. Improved project cost and budgeting risks control | [20] |
| | | **c2** | **Cash flow diagram analysis** | BIM allows comprehensive cash flow analysis by integrating schedule and cost data (4D BIM). This function estimates project funding needs to ensure sufficient funds are available. It helps anticipate cash flow gaps and reduce risk via proactive financial planning. | [39] |
| | | **c3** | **Changes order and rework Management** | BIM's financial impact assessment tools and effective change order management are made more | [20,40] |

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



| | | | | | |
|---|---|---|---|---|---|
| | | | | accessible, reducing the risk of cost escalations. | |
| | | c4 | **Improved Contract, Tendering Process.** | BIM incorporates contract terms and conditions into the project model to improve contract management. This interface controls milestones, payments, and penalties for contract financials, avoiding disputes and ensuring compliance. BIM gives potential contractors comprehensive and accurate project information, lowering financial risks and improving tendering transparency. | [43] |
| | | c5 | **Real-Time Cost Reporting and Lifecycle Cost Analysis** | BIM offers real-time project cost and financial performance updates, detecting economic risks and managing data throughout a building's life, enabling informed decisions to balance early investments with long-term savings. | [41,42] |
| | | c6 | **Financial Prediction and Risk Analysis** | Advanced analytical techniques in BIM enable financial risk analysis and prediction. These tools assist in controlling project risk by simulating financial situations and their effects. | [43] |
| D | **BIM - based time potential** | d1 | **4D Scheduling and Time Visualization** | This helps spot scheduling issues and understand how delays affect the project. BIM's 4D scheduling mixes 3D models with the project schedule to see construction progress. | [40,43] |
| | | d2 | **Monitoring risks in real-time** | BIM links virtual models to construction progress and real-time early warning system data to monitor risk. This enables the immediate detection and resolution of any issues. | [3] |

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



| | | | | | |
|---|---|---|---|---|---|
| | | **d3** | **Time-effect analysis** | BIM provides accurate time impact analysis by examining project schedule changes and delays. This identifies key routes and activities that might delay the project. | [24,35] |
| | | **d4** | **Reduced Schedule Delays** | BIM reduces unexpected project delays by enabling proactive planning, conflict detection, and risk reduction. | [13,14] |
| | | **d5** | **Data-driven decision making** | Data ((e.g., geospatial, structural, environmental) analytics and real-time access improve risk assessments and decision-making | [24] |
| | | **d6** | **Lifecycle Management** | long-term perspective helps identify and mitigate risks associated with building performance, maintenance, and future renovations. | [14] |
| **E** | **BIM - based sustainable capabilities** | **e1** | **Regulatory Compliance and Sustainability Standards** | Automatically verify building code, legal, and sustainability designs. Including sustainability criteria in BIM models helps project teams make informed decisions that fulfill safety, budget, and operational requirements while promoting environmental, economic, and social sustainability. This reduces the risk of non-compliance, fines, and rework. | [8,9] |
| | | **e2** | **Energy efficiency and environmental impact analysis:** | Detailing energy use and environmental effect using BIM aids sustainability. Designers can maximize building performance for LEED and BREEAM. | [27] |
| | | **e3** | **Effective Resource Management and Waste Reduction** | BIM enhances sustainable management by improving time, labor, and material estimates, preventing overestimating or underestimating resource demands, and promoting project | [58] |

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



| | | | | | |
|---|---|---|---|---|---|
| | | | | sustainability by reducing waste and optimizing material and energy use. | |
| | | e4 | **Pollution Monitoring and Evaluation** | BIM's real-time sustainability monitoring and evaluation is a big benefit. This permits continual risk assessment and management throughout the project. BIM can integrate with environmental monitoring tools to track pollution levels in real-time during construction. | [9] |
| **F** | **BIM - based Health and Safety capabilities** | **f1** | **Project-Lifecycle Safety Management** | BIM assists safety management from design to construction and operation, assuring health and safety priority. | [27] |
| | | **f2** | **Incident Tracking** | BIM facilitates the monitoring and documentation of near-misses and incidents, enabling in-depth analysis and the formulation of preventative measures against future occurrences. | [46] |
| | | **f3** | **Work Environment and Monitor workload** | BIM technology can enhance workplace well-being by optimizing natural light, ventilation, and noise, reducing overtime and preventing burnout and stress by promoting a healthy work environment. | [40] |
| | | **f4** | **Increase hazard awareness.** | 3D BIM models provide early hazard detection by visualizing the building site. Simulations may show where equipment and personnel are placed, revealing possible conflicts or Risks. | [31, 56] |

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



| | | | | | |
|---|---|---|---|---|---|
| G | **BIM-based operation and maintenance capabilities** | g1 | **Superior facility management** | Improved O&M Efficiency. Facility management is enhanced by space and comprehensive asset information from BIM. Controlling unexpected behaviors like energy-hungry activities or facilities management problems improves operational efficiency. This proactive building performance management reduces operational inefficiencies and risks. | [20,34] |
| | | g2 | **Proactive Maintenance and Risk Mitigation** | Predictive maintenance. This preventative strategy aims to prevent equipment failure and the resulting expensive repairs, downtime, and safety risks. The real-time performance of equipment may be monitored by integrating BIM data with Building Management Systems BMS. | [19,54] |
| | | g3 | **Enhanced Asset Information Management.** | Improved asset monitoring and visualization, consolidated data repository. BIM models can store component warranties, maintenance instructions, and historical data. This reduces errors from outdated or missing data, allowing facility managers to make smart maintenance and repair decisions. | [34] |
| | | g4 | **Integration of Personnel, Equipment, and Technology:** | Personnel, equipment, technology, and management processes are integrated via BIM. Effective planning, maintenance, repair, and emergency management, addressing workers' fundamental requirements and improving construction project efficiency. | [19,20] |

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



| | | | |
|---|---|---|---|
| g5 | **Enhanced Documentation and Compliance** | Including compliance criteria in the model assures regulatory compliance with standards and legislation. BIM tracks all building alterations and upkeep. Inspections by regulatory organizations need this documentation to ensure that all maintenance actions are code-compliant and limit the risk of non-compliance. | [54,55] |

**References.**


1. Abanda, F. H., Musa, A. M., Clermont, P., Tah, J. H., & Oti, A. H. (2020). A BIM-based framework for construction project scheduling risk management. International Journal of Computer Aided Engineering and Technology, 12(2), 182-218.
2. Ali, K. N., Alhajlah, H. H., & Kassem, M. A. (2022). Collaboration and risk in building information modelling (BIM): a systematic literature review. Buildings, 12(5), 571.
3. Zou, Y., Kiviniemi, A., & Jones, S. W. (2017). A review of risk management through BIM and BIM-related technologies. Safety science, 97, 88-98.
4. Siegrist, M., & Árvai, J. (2020). Risk perception: Reflections on 40 years of research. Risk analysis, 40(S1), 2191-2206.
5. Alaeddini, A. & Dogan, I. (2011). Using Bayesian networks for root cause analysis in statistical process control. Expert Systems with Applications. 38. pp. 11230-11243.
6. Zhang, S., Teizer, J., Lee, J.-K., Eastman, C.M., & Venugopal, M. (2013). Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules. Automation in Construction, 29, 183-195.
7. Abougamil, R. A., Thorpe, D., & Heravi, A. (2023). Investigating the Source of Claims with the Importance of BIM Application on Reducing Construction Disputable Claims in KSA. Buildings, 13(9), 2219.
8. Aladaileh, M. J., Lahuerta-Otero, E., & Aladayleh, K. J. (2024). Mapping sustainable supply chain innovation: A comprehensive bibliometric analysis. Heliyon.
9. Rafindadi, A. D. U., Shafiq, N., & Othman, I. (2022). A conceptual framework for BIM process flow to mitigate the causes of fall-related accidents at the design stage. Sustainability, 14(20), 13025.
10. Meerow, S., & Newell, J. P. (2017). Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit. Landscape and urban planning, 159, 62-75.
11. Dey, P. K. (2012). Project risk management using multiple criteria decision-making technique and decision tree analysis: a case study of Indian oil refinery. Production Planning & Control, 23(12), 903-921.
12. Shen, Y., Xu, M., Lin, Y., Cui, C., Shi, X., & Liu, Y. (2022). Safety risk management of prefabricated building construction based on ontology technology in the BIM environment. Buildings, 12(6), 765.
13. Kerzner, H. (2013). Project management: Case studies. John Wiley & Sons.
14. Smith, P. (2016). Project cost management with 5D BIM. Procedia-Social and Behavioral Sciences, 226, 193-200.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1




15. Vigneault, M. A., Boton, C., Chong, H. Y., & Cooper-Cooke, B. (2020). An innovative framework of 5D BIM solutions for construction cost management: a systematic review. Archives of Computational Methods in Engineering, 27, 1013-1030.
16. Sigalov, K., Ye, X., König, M., Hagedorn, P., Blum, F., Severin, B., ... & Groß, D. (2021). Automated payment and contract management in the construction industry by integrating building information modeling and blockchain-based smart contracts. Applied sciences, 11(16), 7653.
17. Raza, M. S., Tayeh, B. A., Aisheh, Y. I. A., & Maglad, A. M. (2023). Potential features of building information modeling (BIM) for application of project management knowledge areas in the construction industry. Heliyon, 9(9).
18. Azhar, S., Khalfan, M., & Maqsood, T. (2012). Building information modeling (BIM): now and beyond. *Australasian Journal of Construction Economics and Building, The*, *12*(4), 15-28.
19. Liu, T., Zhang, S., & Wang, C. (2021). A BIM-based safety management framework for operation and maintenance in water diversion projects. Water Resources Management, 35(5), 1619-1635.
20. Ganbat, T., Chong, H. Y., & Liao, P. C. (2020). Mapping BIM uses for risk mitigation in international construction projects. Advances in Civil Engineering, 2020, 1-13.
21. Moshtaghian, F., & Noorzai, E. (2023). Integration of risk management within the building information modeling (BIM) framework. Engineering, Construction and Architectural Management, 30(5), 1951-1977.
22. Mtya, A. (2019). Evaluation of Building Information Modelling (BIM) adoption, capability and maturity within South African consulting and construction firms.
23. Khaled, A. J., Panlo, F. G., & Luis, F. G. B. (2020). Factors influencing construction projects delay: An exploratory study at a Jordanian public university. International Congress of Project Management and Engineering, 24, 1-14.
24. Eilers, M., Pütz, C., Helmus, M., Meins-Becker, A. (2020). Don't risk your real estate. Actions to realize efficient project risk management using the BIM method. In: 37th International Symposium on Automation and Robotics in Construction (ISARC 2020).
25. Aladayleh, K.J.; Qudah, S.M.A.A.; Bargues, J.L.F.; Gisbert, P.F. Global trends of the research on COVID-19 risks effect in sustainable facility management fields: A bibliometric analysis. Eng. Manag. Prod. Serv. 2023, 15, 12–28. [Google Scholar] [CrossRef].
26. Gebrehiwet, T., & Luo, H. (2017). Analysis of delay impact on construction project based on RII and correlation coefficient: Empirical study. Procedia engineering, 196, 366-374.
27. Musarat, M. A., Alaloul, W. S., Irfan, M., Sreenivasan, P., & Rabbani, M. B. A. (2022). Health and safety improvement through Industrial Revolution 4.0: Malaysian construction industry case. Sustainability, 15(1), 201.
28. Alfahad, A. A., & Burhan, A. M. (2023). BIM-Supporting System by Integrating Risk Management and Value Management. Engineering, Technology & Applied Science Research, 13(6), 12130-12137.
29. Hassaan, A., Hamza, F., Nikhil, M., & Sufyan, S. (2017). A study in construction delays of residential structures. International Refereed Journal of Engineering Science, 6(6), 42-47.
30. Eskander, R. F. A. (2018). Risk assessment influencing factors for Arabian construction projects using analytic hierarchy process. Alexandria engineering journal, 57(4), 4207-4218.
31. Alzoubi, H. M. (2022). BIM as a tool to optimize and manage project risk management. International Journal of Mechanical Engineering, 7(1).
32. Mohammed, A.A.B.; Haron, A.T. Barriers and Challenges of Building Information Modelling Implementation in Jordanian Construction Industry. Glob. J. Eng. Sci. Res. Manag. 2017, 7, 401–414. [Google Scholar]
33. Hyarat, E., Hyarat, T., & Al Kuisi, M. (2022). Barriers to the implementation of building information modeling among Jordanian AEC companies. Buildings, 12(2), 150.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024 doi:10.20944/preprints202410.1783.v1



34. Yang, C., & Mao, L. (2021). Analysis on risk factors of BIM application in construction project operation and maintenance phase. Journal of Service Science and Management, 14(02), 213.
35. Darko, A., Chan, A. P., Yang, Y., & Tetteh, M. O. (2020). Building information modeling (BIM)-based modular integrated construction risk management–Critical survey and future needs. Computers in Industry, 123, 103327.
36. Parsamehr, M., Perera, U.S., Dodanwala, T.C. et al. A review of construction management challenges and BIM-based solutions: perspectives from the schedule, cost, quality, and safety management. Asian J Civ Eng 24, 353–389 (2023). https://doi.org/10.1007/s42107-022-00501-4.
37. Zou, Y., Kiviniemi, A., Jones, S. W., & Walsh, J. (2019). Risk information management for bridges by integrating risk breakdown structure into 3D/4D BIM. KSCE journal of civil engineering, 23, 467-480.
38. Avendano, J. I., Zlatanova, S., Domingo, A., Perez, P., & Correa, C. (2022). Utilization of BIM in steel building projects: A systematic literature review. Buildings, 12(6), 713.
39. Zhou, W., Whyte, J., & Sacks, R. (2012). Construction safety and digital design: A review. Automation in construction, 22, 102-111.
40. Hamledari, H., McCabe, B., & Davari, S. (2017). Automated computer vision-based detection of components of under-construction indoor partitions. Automation in Construction, 74, 78-94.
41. Chen, L., & Luo, H. (2014). A BIM-based construction quality management model and its applications. Automation in construction, 46, 64-73.
42. Cheng, E. W., Ryan, N., & Chiang, Y. H. (2014). Knowledge and asset management in sustainable civil engineering. The Scientific World Journal, 2014.
43. Shahzad, M., Shafiq, M. T., Douglas, D., & Kassem, M. (2022). Digital twins in built environments: an investigation of the characteristics, applications, and challenges. *Buildings*, *12*(2), 120.
44. Jalaei, F., & Jrade, A. (2014). Integrating building information modeling (BIM) and energy analysis tools with green building certification system to conceptually design sustainable buildings. J. Inf. Technol. Constr., 19, 494-519.
45. Pickering, C., & Byrne, J. (2014). The benefits of publishing systematic quantitative literature reviews for PhD candidates and other early-career researchers. Higher Education Research & Development, 33(3), 534-548.
46. Robin, R. O., Yahya, M. Y., Yassin, A. M., & Masram, H. (2022). Building Information Modelling (BIM) Performance Metrics Using Analytic Hierarchy Process (AHP). Architecture, 10(4), 1538-1546.
47. Alirezaei, S., Taghaddos, H., Ghorab, K., Tak, A. N., & Alirezaei, S. (2022). BIM-augmented reality integrated approach to risk management. Automation in Construction, 141, 104458.
48. Hamid, S. A., & Zainon, N. (2021). Development of BIM capabilities model for Malaysia airport project management. MALAYSIAN CONSTRUCTION RESEARCH JOURNAL (MCRJ), 1.
49. Fernández-Alvarado, J. F., Coloma-Miró, J. F., Cortés-Pérez, J. P., García-García, M., & Fernández-Rodríguez, S. (2022). Proposing a sustainable urban 3D model to minimize the potential risk associated with green infrastructure by applying engineering tools. Science of The Total Environment, 812, 152312.
50. Sanchez, A. X., Hampson, K. D., & Mohamed, S. (2015). Sydney Opera House case study report.
51. Rodrigues, F., Baptista, J. S., & Pinto, D. (2022). BIM approach in construction safety—a case study on preventing falls from height. Buildings, 12(1), 73.
52. Sami Ur Rehman, M., Thaheem, M. J., Nasir, A. R., & Khan, K. I. A. (2022). Project schedule risk management through building information modelling. International Journal of Construction Management, 22(8), 1489-1499.
53. Waqar, A., Othman, I., Shafiq, N., Deifalla, A., Ragab, A. E., & Khan, M. (2023). Impediments in BIM implementation for the risk management of tall buildings. Results in Engineering, 20, 101401.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 October 2024
doi:10.20944/preprints202410.1783.v1




54. Chowdhury, M., Hosseini, M. R., Edwards, D. J., Martek, I., & Shuchi, S. (2024). Comprehensive analysis of BIM adoption: From narrow focus to holistic understanding. Automation in Construction, 160, 105301.
55. Pidgeon, A., & Dawood, N. (2023). Verification and validation of a framework for collaborative BIM implementation, measurement and management (CIMM). Smart and Sustainable Built Environment, 12(4), 847-871.
56. Tan, Y., Xu, W., Chen, P., & Zhang, S. (2024). Building defect inspection and data management using computer vision, augmented reality, and BIM technology. Automation in Construction, 160, 105318.
57. Zou, Y., Kiviniemi, A., & Jones, S. W. (2016). Developing a tailored RBS linking to BIM for risk management of bridge projects. Engineering, Construction and Architectural Management, 23(6), 727-750.
58. Ahmad, D. M., Gáspár, L., Bencze, Z., & Maya, R. A. (2024). The Role of BIM in Managing Risks in Sustainability of Bridge Projects: A Systematic Review with Meta-Analysis. Sustainability, 16(3), 1242.
59. Alshihri, S., Al-Gahtani, K., & Almohsen, A. (2022). Risk Factors That Lead to Time and Cost Overruns of Building Projects in Saudi Arabia. Buildings, 12(7), 902. https://doi.org/10.3390/buildings12070902
60. Aladaileh, M. J., Aladayleh, K. J., Lahuerta-Otero, E., & Cordero Gutiérrez, R. (2024). Leveraging lean and green supplychain practices for sustainable supply chain performance: the moderating role of environmental orientation. Engineering Management in Production and Services, 16(3), 75-97. doi: 10.2478/emj-2024-0025
61. Belcher, E. J., & Abraham, Y. S. (2023). Lifecycle Applications of Building Information Modeling for Transportation Infrastructure Projects. Buildings, 13(9), 2300.
62. Altwassi, E. J., Aysu, E., Ercoskun, K., & Abu Raed, A. (2024). From Design to Management: Exploring BIM’s Role across Project Lifecycles, Dimensions, Data, and Uses, with Emphasis on Facility Management. Buildings, 14(3), 611.
63. Saaty, T. L. (1987). Decision making, new information, ranking and structure. Mathematical Modelling, 8, 125-132.
64. Vargas, L. G. (1990). An overview of the analytic hierarchy process and its applications. European journal of operational research, 48(1), 2-8.
65. Thanki, S., Govindan, K., & Thakkar, J. (2016). An investigation on lean-green implementation practices in Indian SMEs using analytical hierarchy process (AHP) approach. Journal of cleaner production, 135, 284-298.
66. Pun, K. F., & Hui, I. K. (2001). An analytical hierarchy process assessment of the ISO 14001 environmental management system. *Integrated Manufacturing Systems*, *12*(5), 333-345.
67. Munny, A. A., Ali, S. M., Kabir, G., Moktadir, M. A., Rahman, T., & Mahtab, Z. (2019). Enablers of social sustainability in the supply chain: An example of footwear industry from an emerging economy. Sustainable Production and Consumption, 20, 230-242.
68. Tabejamaat, S., Ahmadi, H., & Barmayehvar, B. (2024). Boosting large‐scale construction project risk management: Application of the impact of building information modeling, knowledge management, and sustainable practices for optimal productivity. Energy Science & Engineering, 12(5), 2284-2296