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Implementing Building Information Modeling to Enhance Smart Airport Facility Management: An AHP-SWOT Approach

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Abstract: Airport facility management requires innovative and coordinated techniques due to the infrastructure's complexity, stakeholders' diversity, and the necessity of safety. Adopting building information management (BIM) as an advanced technology has several benefits, including increased productivity, lower cost, and higher quality of service. This study seeks to determine the strategies for using BIM in airport facility management. In this vein, two questionnaires were developed to collect data based on a literature review. The first questionnaire was used to collect data for identifying and ranking the main criteria, and the second questionnaire was used to identify the practical strategies. The experts of this study answered five strengths, four weaknesses, five opportunities, and five threats using a standardized questionnaire. An integrated AHP-SWOT approach was used to identify and examine the practical strategies. Furthermore, a sensitivity analysis was used to ensure the results were correct. The findings showed that smart maintenance management, with a weight of 0.363, was the most important strength in the SWOT analysis. Resistance to change was the most important weakness, with a weight of 0.455. The increasing need for smart airports with a weight of 0.358 was the most important opportunity, while cybersecurity issues with a weight of 0.385 were the most important threat. Integrating BIM into the aviation sector can enhance efficiency and sustainability in airport facility management while addressing potential opportunities and shared hazards that extend beyond airport operations.

Keywords: building information modeling; airport facility management; smart airports; SWOT analysis; smart maintenance management

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1. Introduction

Airport buildings are complex public transportation infrastructures essential for a country's economic, social, and cultural development [1]. These structures must be built and operated to accommodate the large volume of passenger and freight traffic while maintaining safety, service quality, and efficiency [2]. Airport facilities management face a multitude of technical challenges, stakeholder engagement issues, and ongoing legal developments that significantly hinder operational efficiency [3]. One prominent example of a technical challenge is the failure of multiple systems during the opening of Heathrow's Terminal 5, which highlighted the complexities involved in managing airport infrastructure and the critical need for effective stakeholder coordination during such operational phases [4]. Similarly, the computer system outage at Virgin Blue Airlines serves as another illustration of how technical failures can disrupt airport operations, emphasizing the vulnerability of these systems to various disturbances [5].

Stakeholder engagement is crucial in addressing these technical challenges. The Glasgow Airport terrorist attack in 2007 exemplifies the importance of robust crisis management and coordination among stakeholders, as legal and security developments necessitate a comprehensive approach to facilities management [6]. The need for effective communication and collaboration among various stakeholders, including airport authorities, airlines, and security agencies, is paramount to ensuring a swift and coordinated response to crises. Ongoing legal developments also pose significant challenges for airport facilities management. New regulations and compliance requirements can complicate project execution and operational processes, necessitating continuous adaptation by airport management teams [7].

These legal frameworks often evolve in response to emerging threats and public health crises, such as the COVID-19 pandemic, which further underscores the need for resilience in airport operations [8]. Technical challenges extend beyond system failures to include issues like poor network availability and inadequate staffing, which hinder effective project implementation and operational continuity [9]. Additionally, the decentralized waste collection system at airports complicates waste management practices, reflecting broader inefficiencies in facility management. The inability to recycle waste originating from international flights adds another layer of complexity to waste management efforts, highlighting the need for improved systems and processes [10]. Addressing these issues through the effective operation of facilities can enhance resilience and ensure continued operations amidst uncertainties.

Building information modeling (BIM) is a technique for representing a building in a multidimensional way using views of the same model [11]. BIM is a cutting-edge digital technology that facilitates the integration of design, construction, and operational data throughout a project's lifecycle. It supports enhanced decision-making, operational efficiency, safety, and service quality, while also reducing costs. With the latest advancements in BIM, its applications have expanded to include real-time data integration, collaborative workflows, and improved sustainability [12]. The implementation of BIM allows for comprehensive project lifecycle management, which minimizes risks and optimizes processes from the initial design phase to the operational stage of airport facilities [13]. One of the primary advantages of using BIM in airport projects is its ability to improve operational efficiency. BIM facilitates better planning and resource management, which is crucial in the complex environment of airport operations. Additionally, the use of 3D modeling within BIM provides accurate representations of airport facilities, aiding in design visualization and decision-making. This visual clarity helps stakeholders understand the project better, leading to more informed choices. Cost management is another critical aspect where BIM proves beneficial. By tracking and managing costs throughout the construction process, BIM ensures that projects remain within budget, which is vital for large-scale airport developments [14]. Furthermore, BIM's Clash Detection feature identifies and resolves design conflicts before construction begins, significantly reducing the likelihood of costly changes during the building phase [15].

This proactive approach not only saves money but also time, enhancing the overall project efficiency. Collaboration tools embedded in BIM platforms foster effective communication among various stakeholders, including architects, engineers, and contractors. This collaborative environment is essential for successful airport projects, where multiple parties must work together seamlessly [13]. Moreover, the use of data interchange through electronic data interchange documents facilitates smooth communication, ensuring that all parties are aligned and informed throughout the project [16]. Post-construction, BIM continues to play a vital role in facility management. It serves as a knowledge repository for ongoing management and maintenance of airport facilities, thereby improving operational longevity [17]. The predictive capabilities of BIM also contribute to risk mitigation by identifying potential risks early in the construction process, allowing for timely interventions [17]. These benefits can greatly improve the efficiency of airport infrastructure and make it easier to achieve environmental sustainability goals [18].

Although extensive research on BIM exists [18], comprehensive studies of its use in airport construction management are scarce. Several studies have carefully examined BIM's capabilities [19]. However, a large research gap exists in fully analyzing the strengths, weaknesses, opportunities, and threats (SWOT) associated with applying BIM in airport infrastructure. Furthermore, not enough attention has been paid to optimization techniques and prioritization of criteria for the effective deployment of these technologies. Therefore, this study attempts to address this research gap by examining the use of BIM in airport facility management. In this vein, initially, a SWOT analysis determines the domain's strengths, weaknesses, opportunities, and threats. Then, the analytical hierarchy process (AHP) prioritizes the essential criteria, followed by a sensitivity analysis to determine the impact of the weight of different criteria on the results. These findings can help project managers and planners improve BIM implementation and efficiency in operating airport facilities [20].

2. Research Background

This research aims to integrate building information modeling (BIM) into smart airport management, presenting an innovative approach to improve operational efficiency, passenger experience, and overall facility management. This research's main innovation is combining SWOT analysis and analytic hierarchy process (AHP) approaches to evaluate and prioritize different criteria, which have not been comprehensively used in the airport research literature so far. Using sensitivity analysis to assess the effects of variable changes on BIM performance in airport management contributes to informed decision-making, in line with strategic objectives.

Integrating BIM into smart airport management is an innovative approach to improving operational efficiency, passenger experience, and overall facility management [21]. It explores the combination of multicriteria decision-making frameworks, such as SWOT analysis, AHP, and sensitivity analysis, which can be used to evaluate and apply BIM in smart airports.

BIM is an important tool in airport lifecycle management because it enables digitalizing design, construction, and operational processes [22]. BIM simplifies the management of physical and operational data within a common digital framework, which is crucial for advancing smart infrastructure. This technology is demonstrated by Gatwick Airport, where BIM has transformed project delivery and asset management while increasing operational efficiency [23]. The incorporation of BIM into numerous airport designs has produced significant gains in quality assurance, as demonstrated by the Jinan Yaoqiang International Airport Reconstruction Project ("BIM Application in Airport Reconstruction Projects", 2024) [24].

BIM implementation in smart airports requires a deep understanding of the challenges and opportunities. Koseoglu et al. identified significant barriers to BIM implementation in large-scale airport projects, including corporate culture, financial constraints, and partnership issues. In contrast, collaborative partnerships, supportive leadership, and effective information management can all help ensure successful BIM integration [25]. This dual perspective is essential for conducting a SWOT analysis, which enables stakeholders to identify the strengths, weaknesses, opportunities, and threats associated with BIM adoption in airport management.

Also, integrating BIM with other technologies, such as the Internet of Things (IoT) and Geographic Information Systems (GIS), enhances the operational capabilities of smart airports. Integrating BIM and IoT can improve airport pavement management and increase maintenance and operation efficiency [26]. The importance of creating a uniform data environment based on BIM standards to promote interoperability between airport infrastructures has been emphasized. This interoperability is essential for successful decision-making and resource allocation in airport management [27].

Sensitivity analysis is essential to identify how different factors affect the effectiveness of BIM deployment. By measuring the impact of variable changes on performance, stakeholders can make informed decisions aligned with strategic objectives. This analytical method enhances AHP by providing a systematic framework for ranking criteria and alternatives in complex decision-making scenarios [28].

BIM makes airport infrastructure more visible and manageable, allowing stakeholders to analyze better and improve performance metrics [29]. For example, Haribove emphasized the importance of identifying the critical elements that affect airport performance and managing them systematically using an integrated performance management system (IPMS) [30]. This is consistent with the findings of Chang et al., who emphasized the importance of reviewing safety management systems (SMSs) at airports and showed that a structured approach can significantly improve safety performance [31]. Adabii et al. discussed how AHP can help airport authorities prioritize decision-making criteria in safety management, allowing them to align their resources with business objectives [32].

As demonstrated by Merhej and Feng, sensitivity analysis in airport management enables the identification of critical control points in airport operations, which is essential for effective decision-making. This analytical approach can be combined with BIM to assess the effects of various operational parameters on the overall airport performance [33]. For example, Lai et al. demonstrated the use of AHP to assess airport efficiency, which may be improved by using BIM data to influence decision-making processes [34].

Combining BIM and MCDM approaches, such as AHP and SWOT analysis, is helpful for a complete understanding of airport management issues. Zhang and Zhou's work on security information management with fuzzy AHP methodology demonstrated how structured decision-making frameworks can help in complex systems [35]. This is especially true in smart airports, where integrating technology and data analytics is crucial for increasing operational efficiency and safety [36].

The study of airport logistics' competitiveness using AHP emphasized the importance of a systematic approach to analyzing multiple operational elements. This is consistent with the general trend of using MCDM techniques in transportation systems, and Mardani et al. provided a comprehensive review of current research on the subject [37]. The capacity to consider multiple variables simultaneously improves the decision-making capabilities of airport managers and allows for more informed and strategic planning [38].

After reviewing the current literature, we will discuss the innovation of our research, which includes the following statements:

- SWOT and AHP methods have been used to analyze smart airport management. This combination is an innovative method for assessing airport management's strengths, weaknesses, opportunities, and threats.
- The sensitivity analysis method has been used to assess the impact of changes in criteria weights, which helps better understand the impact of changes in criteria prioritization.
- Providing a framework for implementing building information modeling in airports can be used for better management and guidance for managers and engineers in real projects.

A brief comparison of this research with previous studies is provided in Table 1 for a better and clearer comparison. This comparison was divided into sections on methodology, scope of study, sensitivity analysis, and practical guidance for implementing building information modeling.

Table 1. A brief general comparison of this research with previous studies (Authors).

Feature	Previous Studies	This Research
Methodology	Independent methods (SWOT, AHP, or ANP) are usually used.	Combination of SWOT + AHP + sensitivity analysis.
Field of research	Public and commercial buildings.	Smart airports.
Examining the effects of changes in criteria weights	Less investigated.	Conduct sensitivity analysis to assess the impact of changes in criteria weights.
Providing practical solutions for implementation	More on a conceptual and theoretical level.	Providing a practical framework for implementing BIM in airports.

In Figure 1, the presented graphical framework was developed based on the research review. The framework visually organized the main themes, relationships, and related subcategories to provide a better understanding of the connection between key concepts and their applications in smart airport management.

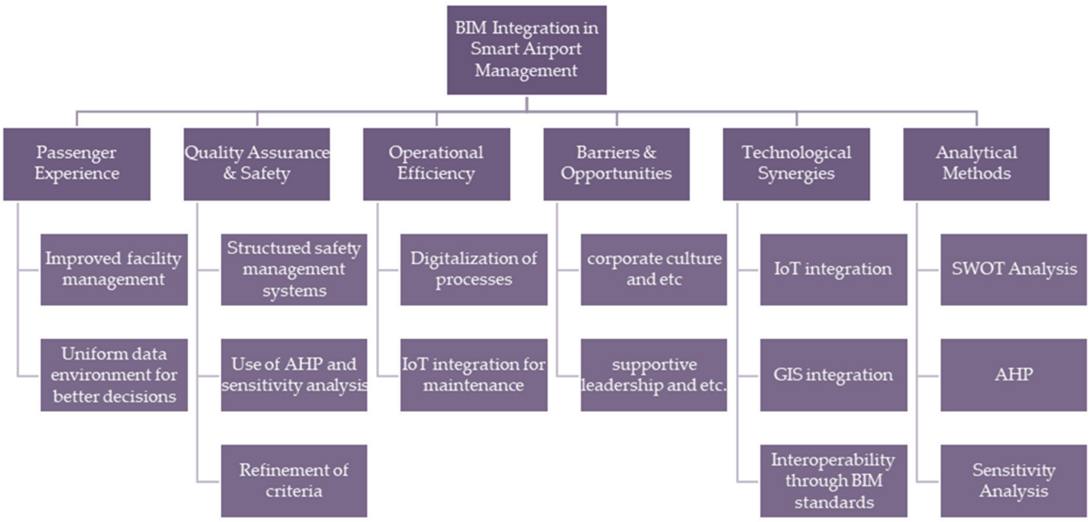

Figure 1. Graphical framework for research background.

3. Research Method

This research used an applied method based on the purpose of using BIM, classified as descriptive based on thematic characteristics, as survey research in terms of data collection timing, and as field research in terms of information collection methods. The statistical population of this research included managers, experts, and specialists involved in airport management and various related projects with the necessary expertise and knowledge about BIM applications in this field. Considering the specialization of the research and the use of methodologies, such as SWOT and AHP, that rely on expert judgment, the statistical population was estimated to be between 5 and 20 people. Also, sensitivity analysis was used to assess the robustness of the results obtained from the analytic hierarchy process (AHP) technique. This analysis was performed to assess the impact of any change in the weights of the criteria on the final ranking. This analytical tool facilitates more accurate and optimal decision-making in airport facility management.

Figure 2 illustrates a flowchart of the research process. The flowchart started with the “Start” step and progressed to the “Research Similarities” stage, thoroughly examining prior studies to offer context for the current research. The second stage, “Extract Four Criteria from Research History", entailed identifying and categorizing the SWOT framework's key components: strengths, weaknesses, opportunities, and threats. The collected criteria were then ranked across the four SWOT domains using the analytic hierarchy process (AHP) to determine their importance. Sensitivity analysis was used to "confirm the results" in the previous stage, and the process then continued to "Perform SWOT Analysis to Find Research Areas", where the data were analyzed to identify areas that needed improvement or extra investigation. The next level was "Discussion of Studies Conducted in the Established Field of the Research Domain", which assessed the findings in light of the current body of knowledge. The flowchart concluded with the "End" stage.

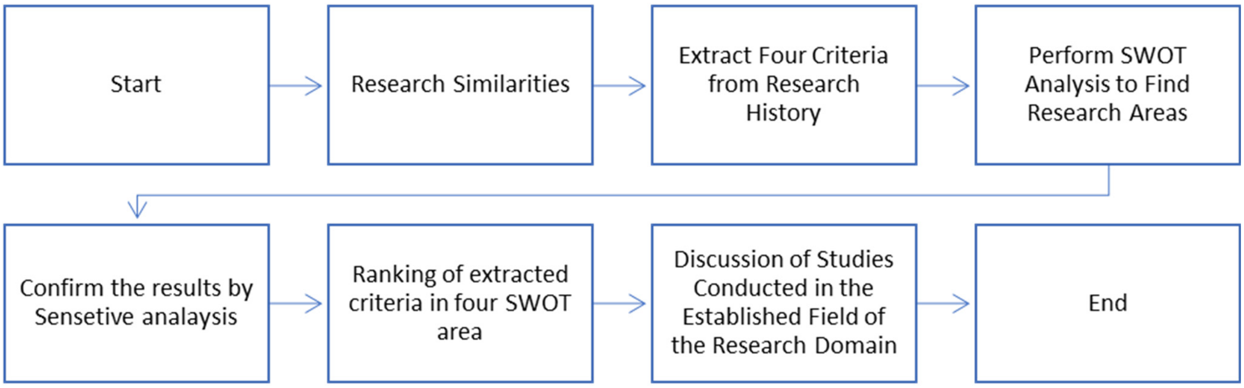

Figure 2. Flowchart of how we conducted the research (Authors).

3.1. Questionnaire Design and Details

Snowball sampling was used due to the difficulty of accessing experts in specialized research. This strategy involved identifying and selecting experts, who were then asked to introduce others with similar characteristics, thus facilitating a more rapid chain sampling process. Then, an analytic hierarchy process (AHP) questionnaire was used, specifically designed to collect opinions on smart airport management using building information modeling. In this method, criteria were compared in pairs. The designed questionnaire included pairwise comparison tables in which experts were asked to determine the relative importance of each pair of criteria based on a standard AHP numerical scale (from 1 to 9). This scale was designed to convert quantitative and qualitative comparisons into numbers. The data obtained from the questionnaire were analyzed to form pairwise comparison matrices and extract the relative weights of each criterion. The questionnaire was designed and sent to experts in October 2024, and data were collected in November 2024. The questionnaires were distributed electronically to ensure the accessibility and confidentiality of the selected experts.

All tables related to the paired comparison questionnaires for different criteria in this study are included in Tables A1–A4. These tables include paired comparisons for four categories of criteria: strengths, weaknesses, opportunities, and threats. These comparisons were made for prioritization and decision-making in the analytical hierarchy process (AHP).

3.2. Experts' Choice

The selection of ten experts for this study was based on the necessity for expert analysis. Given the study's specialized nature, ten experts' responses were sufficient to meet the study's objectives. The number of experts actively working on the topic and the difficulty in reaching them due to confidentiality limitations resulted in the utilization of the opinions of ten experts. These specialists have substantial experience in the relevant topic. Their suggestions drew on their professional expertise and experience in airport-related research, ensuring that their contributions were credible and directly connected to the study objectives. The variety of their experiences extended the research findings and presented a more complete picture.

3.3. Integration of SWOT, AHP, and Sensitivity Analysis

The combination of SWOT and AHP provided a structured and quantitative strategy for assessing BIM adoption in airport construction. SWOT categorizes internal (strengths and weaknesses) and external (opportunities and threats) components, whereas AHP weights these factors using pairwise comparisons, ordering them according to their importance.

This combination focuses on crucial areas, such as infrastructure difficulties and innovation opportunities. Sensitivity analysis validates the results by examining how changes in input weights influence outcomes. These methodologies provide a solid foundation for strategic decision-making in airport development projects.

SWOT analysis, often known as a SWOT matrix, is a strategic planning tool used to help individuals or organizations identify strengths, weaknesses, opportunities, and threats related to company rivalry or project planning. SWOT theory states that strengths and weaknesses are typically internal, whereas opportunities and threats are frequently external. Table 2 illustrates the four parameters analyzed by the technique.

Table 2. All criteria in SWOT analysis (Authors).

SWOT	Criteria	Description	Source/s
Strengths	Project Information Integration	Integration is critical for managing the multidimensional nature of airport development, which requires multiple systems and technologies to work in tandem.	[39]
	Increased Design Accuracy	Accuracy enhances the design process and minimizes costly changes during construction.	[40]
	Improved Time and Cost Management	Capability is essential for airport projects, where delays and budget overruns can have significant repercussions.	[41]
	Advanced Simulation and Analysis	Predictive analysis is vital for ensuring that the airport can handle expected traffic volumes and operational challenges effectively.	[41]
	Smart Maintenance Management	Use of BIM in maintenance management allows for a seamless transition from construction to facility management.	[42]
Weaknesses	High Initial Cost	The long-term return on investment (ROI) may not be immediately apparent, leading to skepticism among decision-makers regarding the viability of BIM adoption.	[43]
	High Technical Expertise Required	Organizations may face challenges in recruiting or training staff, further complicating the adoption process.	[44]
	Resistance To Change	Resistance is crucial for the successful integration of BIM, necessitating comprehensive change management strategies that include stakeholder engagement and communication.	[45]
	Dependence on Advanced Equipment	The reliance on advanced equipment can create vulnerabilities, particularly in the event of system failures or cyber threats, which can disrupt airport operations.	[46]
Opportunities	Development of Smart Technologies	IoT devices can monitor passenger flow and optimize resource allocation, while AI can predict maintenance needs, thereby reducing downtime.	[47]
	Growing Demand for Smart Airports	Airports are now prioritizing the integration of smart technologies to meet these demands.	[47]
	New Rules and Standards	Compliance with these standards not only enhances operational capabilities but also fosters international collaboration.	[48]
	Increased Competitiveness	As airports strive to differentiate themselves in a competitive landscape, the adoption of smart technologies becomes a strategic imperative.	[49]
	Improved Environmental Sustainability	Supports sustainable design practices by enabling the simulation of energy performance and resource consumption during the planning and construction phases.	[50]
Threats	Economic Fluctuations	The implementation of BIM can enhance the resilience of airport infrastructure, enabling better responses to economic downturns by streamlining operations and reducing waste.	[51]
	Non-Compliance with Local Laws	The collaborative nature of BIM fosters better communication among stakeholders, which is essential for maintaining compliance with local regulations.	[52]
	Domestic and Foreign Competition	The ability to visualize and analyze airport layouts and operations in real time allows for quicker decision-making and adaptation to market changes, thus positioning airports favorably against their competitors.	[53]
	Cyber Risks	By utilizing BIM, airports can implement robust security protocols that protect sensitive information and infrastructure from cyber threats, thereby ensuring operational continuity and safety.	[54]
	Rapid Technological Changes	The use of BIM can streamline the process of adopting new technologies, reducing the time and cost associated with implementation.	[55]

The concept of strategic fit expresses the degree of compatibility of the internal and external environments (Table 3). Identifying SWOT is important because it allows people and organizations to plan the next steps to achieve the goal.

Table 3. SWOT naming analysis.

Category	Description
Strengths (S)	Characteristics of the business or project that provide it an advantage over competitors.
Weaknesses (W)	Characteristics that put the business or project at a disadvantage compared to others.
Opportunities (O)	These are environmental elements that the business or project might benefit from.
Threats (T)	These are environmental elements that can cause problems for the business or project.

Table 4 highlights the strategic approaches—Maximax (SO), Minimax (WO), Maximin (ST), and Minimum (WT)—designed to address the interplay between internal factors (strengths and weaknesses) and external factors (opportunities and threats).

Table 4. Different areas of the SWOT method.

	Destructive	The builder
Internal factors	W (weaknesses)	S (strengths)
External factors	T (threats)	O (opportunities)

3.4. Calculation of the Matrix of External and Internal Factors

Table 5 illustrates the methodical procedure of creating the external factors' evaluation (EFE) and internal factors' evaluation (IFE) matrices. The procedures, which included identifying and categorizing external elements, assigning weights, scoring replies, and computing weighted scores, give a clear framework for evaluating an organization's strategic position.

Table 5. Strategic approaches derived from SWOT analysis.

Strategies	Descriptions
SO strategy (Maximax strategy)	This strategy aims to maximize external opportunities by focusing on the identified strengths.
WO strategy (Minimax strategy)	This strategy uses existing opportunities to reduce the effects of the organization's weaknesses.
ST strategy (Maximin strategy)	This strategy focuses on what measures should be taken to overcome (reduce or eliminate) the threats outside the organization by using the organization's strengths and capabilities.
WT strategy (Minimum strategy)	This strategy aims to determine what decisions should be made to minimize the organization's weaknesses against the identified threats.

3.5. AHP (Analytic Hierarchy Process) Method

It is necessary to use suitable methods for multicriteria decision-making. In this research, according to the structure and relationship between the main criteria, the goal, and the sub-criteria, the AHP model, a subset of the network analysis methods (analytic network process (ANP)), was used.

Table 6 explains the step-by-step procedure for implementing the AHP method, from designing pairwise comparison questionnaires to calculating inconsistency rates. A similar procedure has been applied by many other related works in the construction industry. The final weights and rankings were verified for consistency and supported decision-making.

Table 6. Steps for constructing the EFE and IFE matrices.

Step	Matrix of External Factors (EFE) and Matrix of Internal Factors (IFE)
First step	After identifying the external environmental factors and preparing a list of them, the list is extracted with the help of experts' opinions. These factors should be based on facts and be as accurate as possible, and then they should be separated into two categories: opportunities and threats.
Second step	Assign each factor a weighted coefficient between zero (unimportant) and one (extremely important). The sum of allocated weight coefficients must be equal to one. The coefficients represent the relative relevance of the researched factors.
Third step	Write a score between 1 and 4 for each factor according to the company's compliance with opportunities and threats. This score shows the effectiveness of the company's current strategies in showing the reaction to the mentioned factors. The interpretation of each of the points can be as follows: 4: Golden opportunity (excellent response) 3: Considerable opportunity (good response) 2: Considerable threat (bad and negative reaction) 1: Serious threat (very bad reaction).
Fourth step	Calculate the weighted score of each factor.
Fifth step	It calculates the weighted score of the organization, which is at least one and at most four.

Table 7 presents the scoring system used in pairwise comparisons for the analytical hierarchy process (AHP). The scale ranged from 1 (equal importance) to 5 (absolute preference), with intermediate values (e.g., 6) representing nuances in preference levels. This scoring system helped quantify expert judgments to prioritize options effectively.

Table 7. Steps of the analytical hierarchy process (AHP) method.

Step	AHP Method
First step	Designing a paired questionnaire and having experts complete it.
Second step	Scoring the questionnaires based on the range of changes from 1 to 9, which are described in the following Table 8
Third step	Using the experts' matrix values, these matrices are calculated as a geometric mean in each region and entered into the Expert Choice software. The ranking results and weights are calculated for each one. One of the matrices is selected, and then, by multiplying the weights in them, the final ranking is obtained.
Fourth step	The inconsistency rate must be less than 10% and is calculated using the following relationships: Calculation of the normalized values of the matrix of pairwise comparisons (A) using the arithmetic mean method (W; Table 8): $\lambda = A.W$ (1) Formula (1) is used to evaluate the importance of criteria, where λ represents the eigenvalue of the pairwise comparison matrix A and W represents the vector of weights or priorities of the criteria. $\lambda_{\max_i} = \frac{[A.W]_i}{W_i}$ (2) Formula (2) is related to calculating the eigenvalue of the largest pairwise comparison matrix, where $\lambda_{\max}$ is the largest eigenvalue of the pairwise comparison matrix, A is a pairwise comparison matrix, W is the vector of weights, and W_i is the weight associated with each criterion. $\lambda_{\max} = \frac{\lambda_{\max_1} + \lambda_{\max_2} + \ldots + \lambda_{\max_n}}{n}$ (3) In Formula (3), we calculate the average eigenvalue of the largest pairwise comparison matrix, where $\lambda_{\max}$ is the average of the eigenvalues of the largest matrices, $\lambda_{\max\ 1.2\ldots}$ is the largest eigenvalue for each pairwise comparison matrix, and n is the number of pairwise comparison matrices whose eigenvalues have been calculated. $I.I = \frac{\lambda_{\max} - n}{n-1}$ (4) Formula (4) is used for calculating the compatibility index, I.I, where $\lambda_{\max}$ is the largest eigenvalue of the pairwise comparison matrix, and n is the number of pairwise comparison matrices. $I.R = \frac{I.I}{I.I.R} < 0.1 \rightarrow Ok$ (5) Formula (5) is related to the consistency ratio (I.R), which is used to evaluate the consistency in the pairwise comparison matrix, where I.R is the relative compatibility index, I.I is the compatibility index that has been calculated previously, and I.I.R is the compatibility index of random values that are extracted from standard tables for a certain number of criteria.
Fifth step	If the inconsistency rate is correct, the output of the weights will be accepted through the software.

Table 8. Scoring in pairwise comparisons.

Value	Comparison Status of i with Respect to j	Explanation
1	Same preference	Index i is of equal importance to j or they are not preferred to each other.
2	Slightly preferred	Index i is slightly more important than j.

Table 8. *Cont.*

Value	Comparison Status of i with Respect to j	Explanation
3	Very preferred	Index i is more important than j.
4	Very much preferred	Index i is much more preferable than j.
5	Absolutely preferred	Index i is absolutely more important than j and not comparable to j.
6	In between	It shows intermediate values, for example, 8 indicates a higher importance than 7 and lower than 9 for i.

Table 8 lists the random index (I.I.R) coefficients used in calculating the consistency ratio for the AHP method. The values correspond to the matrix size (N) and served as a benchmark to ensure the consistency of pairwise comparison matrices. A consistency ratio below 0.1 indicates acceptable consistency

3.6. Sensitivity Analysis

Sensitivity analysis is a technique for defining the range of potential outcomes associated with a decision. It is particularly useful in situations characterized by uncertainty about important aspects. Because of the potential interaction of several factors, sensitivity analysis is usually performed using computer software. Sensitivity analysis investigates the effect of output variables on input variables in a statistical model. In other words, it is a methodology for methodically modifying the inputs of a statistical model to predict the impact of these changes on the model's output.

Table 9 shows the essential stages of sensitivity analysis, which begin with data collection to assure accuracy and then identify crucial variables that substantially impact project outcomes. Finally, choosing an appropriate method based on the project type and data allows a thorough grasp of potential risks and opportunities.

Table 9. Coefficients of I.I.R.

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
I.I.R	0	0	0.52	0.88	1.1	1.24	1.34	1.4	1.44	1.48	1.51	1.53	1.55	1.57	1.58

Table 10 presents the sensitivity analysis across three distinct stages.

Table 10. Stages of sensitivity analysis in project evaluation.

Stage	Sensitivity Analysis
First stage	Data gathering is the first stage. This stage collects project-related data, such as costs, revenues, and other performance variables. The data must be accurate and reliable, as their quality and correctness will directly affect the analysis outcomes.
Second stage	After gathering the data, we identify the main variables. The key variables are the parameters that most impact the project's final results. This stage necessitates careful attention to issues that can create large changes in the analysis. Identifying these variables allows analysts to focus on important features.
Third stage	The proper method is determined by the type of project and data collected. This option can assist analysts in acquiring a better understanding of the project's potential and dangers.

4. Results and Discussions

Descriptive statistics will be used to explain and evaluate the data obtained from the sample via questionnaire. The SWOT analysis was used to evaluate the integration of BIM and blockchain for data management in Martian buildings, with the results shown below.

We used the AHP technique to calculate the weights of each item offered to the experts, such as strengths, weaknesses, opportunities, and threats. The study's specialists completed a paired questionnaire to calculate the weights of each issue, which are listed below. First, a paired test was utilized to assess strengths. Based on the studies conducted using the relationships presented in the previous section for the inconsistency rate, the inconsistency rate of this matrix was calculated to be approximately 3%, which is within the standard and permissible range, allowing the results to be expanded and presented more confidently.

- Strengths

Table 11 illustrates the pairwise comparisons of the identified strengths, where criteria such as smart maintenance management (C1), advanced simulation and analysis (C2), and others are compared relative to each other. The numerical values represent the relative importance of one criterion over another, forming the basis for calculating priority weights in decision-making.

Table 11. Strengths and their corresponding criteria (Authors).

Code	Criterion
C1	Smart maintenance management
C2	Advanced simulation and analysis
C3	Design accuracy enhancement
C4	Information integration
C5	Time and cost management

In Table 12 Given that the decision matrix presented by the experts has a low inconsistency rate, the weighting provided by the AHP method can be presented with high confidence of accuracy.

Table 12. Pairwise comparisons of strengths (Authors).

Criterion	C1	C2	C3	C4	C5
C1	1	2	3	4	1.5
C2		1	1.7	3.5	2.5
C3			1	2.2	1.1
C4				1	3
C5					1

In the table above, the final weight of each criterion was determined to indicate how important each criterion is. These weights were based on the decision matrix supplied and derived by normalizing and averaging the column values.

Table 13 shows the sensitivity analysis of criteria weights under ±10% modifications and their original values. It demonstrates how weight variations influenced the priority ranking of strengths, such as smart maintenance management and advanced simulation and analysis, ensuring robust decision-making across various scenarios.

Table 13. Final weights of strengths (Authors).

Rank	Object	Weight
1	Smart maintenance management	0.36
2	Advanced simulation and analysis	0.25
3	Information integration	0.148
4	Design accuracy enhancement	0.145
5	Improved time and cost management	0.091

According to Table 14, The AHP model was highly stable, with all criteria maintaining their ranking positions despite ±10% weight changes. Criteria with lower weights, such as "improved time and cost management" (starting weight: 0.091), may be more responsive to larger adjustments. However, they remained consistent throughout the analysis. The criterion "smart maintenance management" had the highest value and the greatest influence on weight changes, with a starting weight of 0.36. The sensitivity analysis also showed that the results of weighting the strength criteria were not affected by small weight changes, and the ranking structure was consistent. Criteria with greater weights were favored, whereas lower-weight options retained their positions even when modest adjustments were made.

Table 14. Weight change table and sensitivity analysis (Authors).

Criterion	Original Weight	−10% Change	+10% Change	Change in Priority Ranking
Smart maintenance management	0.36	0.32	0.4	No Change
Advanced simulation and analysis	0.25	0.22	0.27	No Change
Design accuracy enhancement	0.145	0.13	0.15	No Change
Information integration	0.148	0.133	0.16	No Change
Improved time and cost management	0.091	0.082	0.1	No Change

Figure 3 illustrates the effect of 10% changes in the criteria's weights on the priority rankings, indicating whether the criteria were relatively stable or sensitive to weight changes.

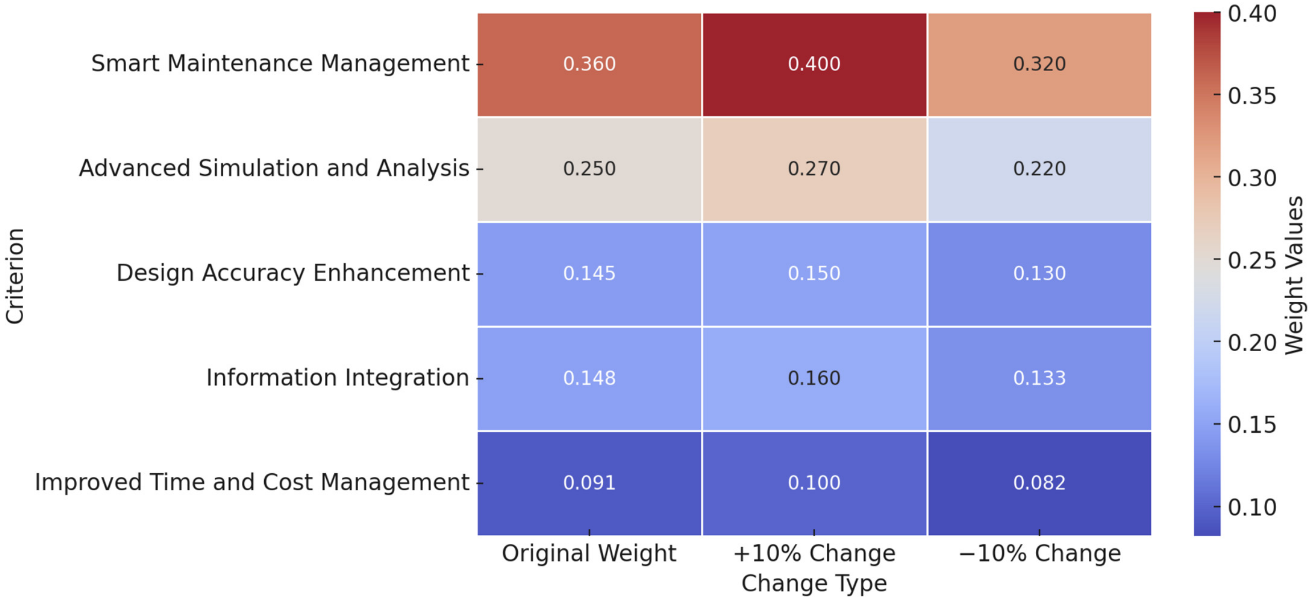

Figure 3. Changes in criteria priority ranking versus weight changes (Authors).

- Weaknesses

Table 15 displays the pairwise comparison among the identified weaknesses, with criteria such as resistance to change (C1), dependency on advanced equipment (C2), and others. The values quantify the relative importance of each criterion, enabling a structured evaluation for prioritization and mitigation planning.

Table 15. Weaknesses and their corresponding criteria (Authors).

Code	Criterion
C1	Resistance to change
C2	Dependency on advanced equipment
C3	High initial cost
C4	High technical expertise requirement

In the Table 16, the final weight of each criterion has been determined to indicate how important each criterion is. These weights are based on the decision matrix supplied and derived by normalizing and averaging the column values.

Table 16. Pairwise comparison of weaknesses (Authors).

Criterion	C1	C2	C3	C4
C1	1	3	2.5	4.5
C2		1	2.7	3
C3			1	2.8
C4				1

Table 17 illustrates a sensitivity analysis of the weights for the highlighted flaws. The graph displays the original weights, the consequences of ±10% adjustments, and their impact on priority rankings. The research demonstrated no change in the priority ranking of criteria, indicating that the weight assignments were stable and reliable.

Table 17. The final weights of weaknesses (Authors).

Rank	Criterion	Weight
1	Resistance to change	0.45
2	Dependency on advanced equipment	0.25
3	High initial cost	0.17
4	High technical expertise requirement	0.11

According to sensitivity analysis in Table 18, adjusting weights by ±10% did not affect the criteria ranking. All criteria stayed in the same placements, showing that the model was rather stable. The resistance to change (0.45) criterion maintained the most significant weakness, regardless of weight. Depending on modern equipment (0.25) was ranked second and maintained that position despite weight fluctuations. The high starting cost (0.17) was less significant than the key criterion but remained third. High technical competence was required (0.11). Because it had the lowest weight, it was rated last, and weight adjustments had no discernible effect on its place. Regardless of weight modifications, none of the criteria shifted in rank. This demonstrates the weight system's resilience to slight adjustments. Resistance to change and reliance on modern equipment were two major threats requiring increased readiness. The weighting model demonstrated that the decision-making structure remained stable even as the weights changed.

Table 18. Sensitivity analysis of weaknesses' weights (Authors).

Criterion	Original Weight	Change −10%	Change +10%	Change in Priority Ranking
Resistance to change	0.45	0.41	0.50	No Change
Dependency on advanced equipment	0.25	0.23	0.28	No Change
High initial cost	0.17	0.15	0.18	No Change
High technical expertise requirement	0.11	0.10	0.12	No Change

Figure 4 shows the impact of weight changes (+10% and −10%) on the ranking of challenging criteria, such as high initial cost and resistance to change.

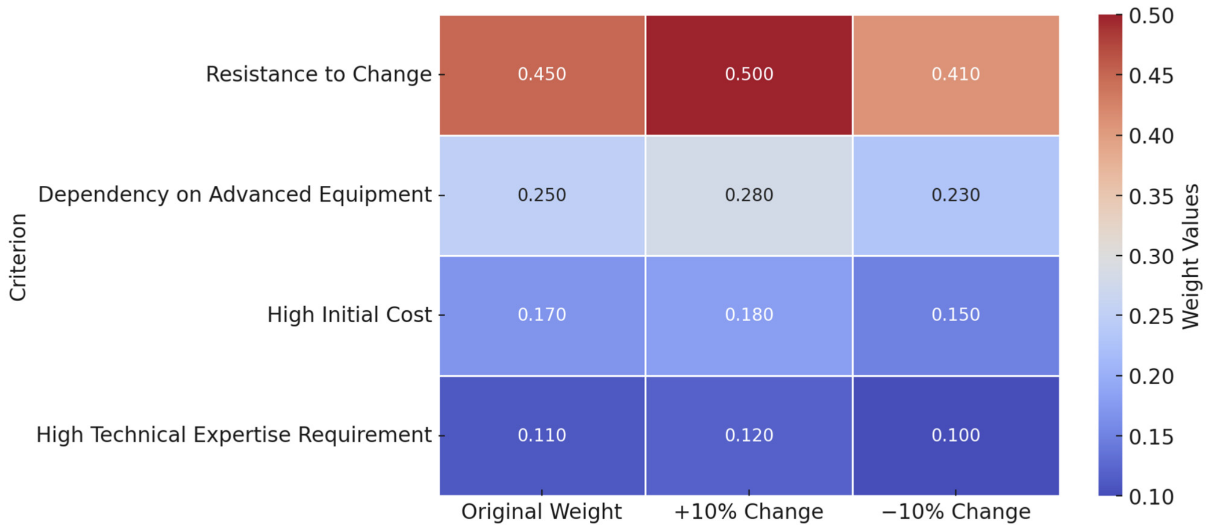

Figure 4. Analyzing the impact of weight changes on the ranking of weakness criteria (Authors).

- Opportunity

Table 19 shows potential development opportunities, such as the growing demand for smart airports (C1) and development of smart technologies (C2). The values indicate the relative importance of each opportunity criterion, allowing for prioritization in strategic planning.

Table 19. Opportunities and their corresponding criteria (Authors).

Code	Criterion
C1	Growing demand for smart airports
C2	Development of smart technologies
C3	Increasing competitiveness
C4	Improving environmental sustainability
C5	New laws and standards

Table 20 summarizes the final weights and rankings of the identified opportunities. Growing demand for smart airports ranked highest, followed by development of smart technologies, while improving environmental sustainability held the lowest rank, reflecting their relative importance in strategic planning.

Table 20. Pairwise comparison of opportunity points (Authors).

Criterion	C1	C2	C3	C4	C5
C1	1	2.5	2	3.5	3
C2		1	2.3	3	2.8
C3			1	2.7	2.4
C4				1	1.8
C5					1

Table 21 presents a sensitivity analysis of opportunity weights, including the initial weights, the consequences of ±10% adjustments, and the influence on priority rankings. The research showed no change in the priority rankings, guaranteeing that the weight allocations remained stable and reliable for strategic planning.

Table 21. The final weights of opportunities (Authors).

Rank	Criterion	Weight
1	Growing demand for smart airports	0.35
2	Development of smart technologies	0.24
3	Increasing competitiveness	0.16
4	New laws and standards	0.12
5	Improving environmental sustainability	0.09

According Table 22, Changing weights by ±10% did not change the ranking of the criteria. All criteria stayed in the same placements, showing that the model was rather stable. Demand for smart airports is increasing (0.35). With the highest weight, it remained the most essential criterion and was steady as the weight changed. The expansion of smart technologies (0.24) was the second most important criterion, and weight changes did not affect the ranking. Criteria such as enhancing environmental sustainability (0.09) and enacting new rules and standards (0.12) remained steady despite weight reductions, although they may be more vulnerable to bigger adjustments. Higher-weighted components, such as demand growth and technological advancement, significantly affected the study, with a weight difference of ± 10%. Criteria with lower weights (such as improving environmental sustainability) remained important, although their position in the rankings was not altered. The weighting system was stable, and weight changes of up to 10% did not affect evaluations. Strategic planning should emphasize essential issues, such as increased demand for smart airports and technological improvements. Other elements require consideration but are less crucial than the basic ones.

Table 22. Changing weights and sensitivity analysis (Authors).

Criterion	Original Weight	Change −10%	Change +10%	Change in Priority Ranking
Increasing competitiveness	0.16	0.15	0.18	No Change
Improving environmental sustainability	0.09	0.08	0.10	No Change
Development of smart technologies	0.24	0.22	0.27	No Change
Growing demand for smart airports	0.35	0.32	0.39	No Change
New laws and standards	0.12	0.11	0.14	No Change

Figure 5 focuses on how weight changes (+10% and −10%) affected prioritizing criteria, including new legislation, demand for smart airports, and the development of new technologies.

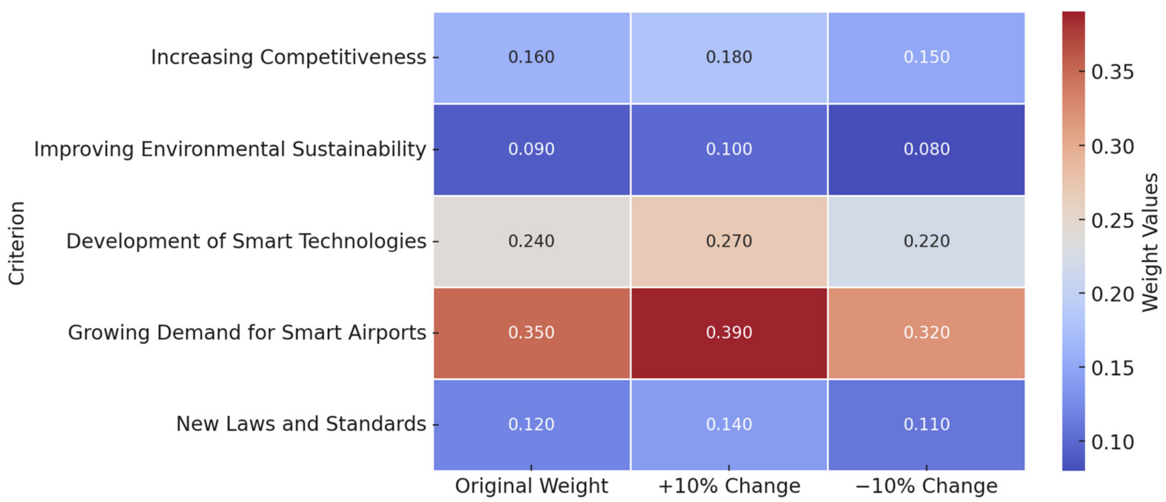

Figure 5. Analyzing changes in the priority of opportunity criteria (Authors).

- Threats

Table 23 presents the pairwise comparison of threats, including cybersecurity risks (C1), economic fluctuations (C2), and others. The numerical values represent the relative importance of each threat criterion, forming a foundation for prioritizing mitigation strategies.

Table 23. Threats and their corresponding criteria (Authors).

Code	Criterion
C1	Cybersecurity risks
C2	Economic fluctuations
C3	Domestic and international competition
C4	Rapid technological changes
C5	Non-compliance with local regulations

Table 24 summarizes the final weights and rankings of the identified threats. Cybersecurity economic fluctuations were a significant threat, followed by economic fluctuations, while non-compliance with local regulations held the lowest rank, reflecting their relative impact on strategic decision-making.

Table 24. Pairwise comparison of threat points (Authors).

Criterion.	C1	C2	C3	C4	C5
C1	1	2.3	2.8	3.2	3
C2		1	1.7	2.3	2.7
C3			1	1.8	2.2
C4				1	1.9
C5					1

Table 25 shows a sensitivity analysis of the weights assigned to identified concerns, which included cybersecurity risks and economic fluctuations. The analysis revealed the initial weights and the impact of $\pm 10\%$ adjustments and confirmed that the priority rankings were unchanged, indicating the resilience and consistency of the review method.

Table 25. The final weights of threats (Authors).

Rank	Criterion	Weight
1	Cybersecurity risks	0.38
2	Economic fluctuations	0.23
3	Domestic and international competition	0.16
4	Rapid technological changes	0.12
5	Non-compliance with local regulations	0.08

Changing the weights by $\pm 10\%$ did not change the ranking of the criteria. All criteria remained in their same placements, showing that the model was quite stable. Cyber hazards (0.38) continued to be the most significant danger. This criterion's position was also unaffected by weight changes. Economic fluctuations (0.23) were the second most significant concern and stayed stable in the sensitivity analysis. Despite weight modifications, the lower-weighted criteria domestic and global competition (0.16) and rapid technical advancement (0.12) remained in place. Non-compliance with local rules (0.08) had the lightest weight and held its position despite weight fluctuations. Higher-weighted factors (e.g., cyber hazards and economic swings) considerably impacted the study, as seen by a $\pm 10\%$ weight change. Lower-weighted criteria, such as non-compliance with local regulations, did not affect the rankings due to their low weight. The sensitivity analysis model demonstrated the stability of decision-making in the presence of weight changes. Prioritizing cyber risks and economic changes is crucial for the risk management strategy. Other factors demand attention but are less important than the core ones.

Figure 6 shows the impact of weight changes (+10% and −10%) on prioritizing challenges, such as non-compliance with local regulations, rapid technological change, domestic and international competition, economic volatility, and cybersecurity risks.

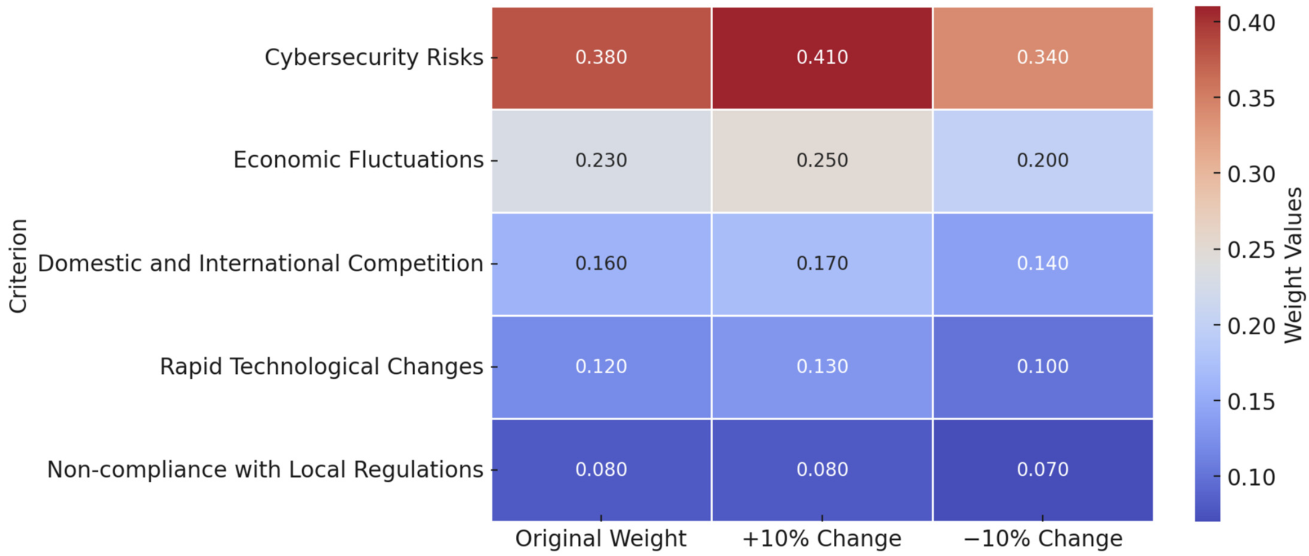

Figure 6. The impact of weight changes on threat prioritization (Authors).

Table 26 summarizes the final weights of the criteria from strengths, weaknesses, opportunities, and threats. Each area focuses on the most relevant elements, such as smart maintenance management (strengths), resistance to change (weaknesses), growing demand for smart airports (opportunities), and cybersecurity risks (threats), offering a comprehensive perspective for strategic prioritization.

Table 26. Changing weights and sensitivity analysis (Authors).

Criterion	Original Weight	Change −10%	Change +10%	Change in Priority Ranking
Cybersecurity risks	0.38	0.34	0.41	No change
Economic fluctuations	0.23	0.20	0.25	No change
Domestic and international competition	0.16	0.14	0.17	No change
Rapid technological changes	0.12	0.10	0.13	No change
Non-compliance with local regulations	0.08	0.07	0.08	No change

Table 27 illustrate Final weights of all points in strengths, weaknesses, opportunities, and threats. Also, in Figure 7 shows the weighting of the criteria in the four categories of strengths, weaknesses, opportunities, and threats, and indicates the relative importance of each criterion in decision-making.

Table 27. Final weights of all points (strengths, weaknesses, opportunities, and threats) (Authors).

Category	Criterion	Final Weight
Strengths	Smart maintenance management	0.363
	Advanced simulation and analysis	0.251
	Data integration	0.148
	Improved design accuracy	0.145
	Better time and cost management	0.091

Table 27. *Cont.*

Category	Criterion	Final Weight
Weaknesses	Resistance to change	0.455
	Dependency on advanced equipment	0.258
	High initial cost	0.172
	High technical expertise requirement	0.113
Opportunities	Growing demand for smart airports	0.358
	Development of smart technologies	0.246
	Increasing competitiveness	0.168
	New laws and standards	0.127
	Improving environmental sustainability	0.098
Threats	Cybersecurity risks	0.385
	Economic fluctuations	0.233
	Domestic and international competition	0.1674
	Rapid technological changes	0.124

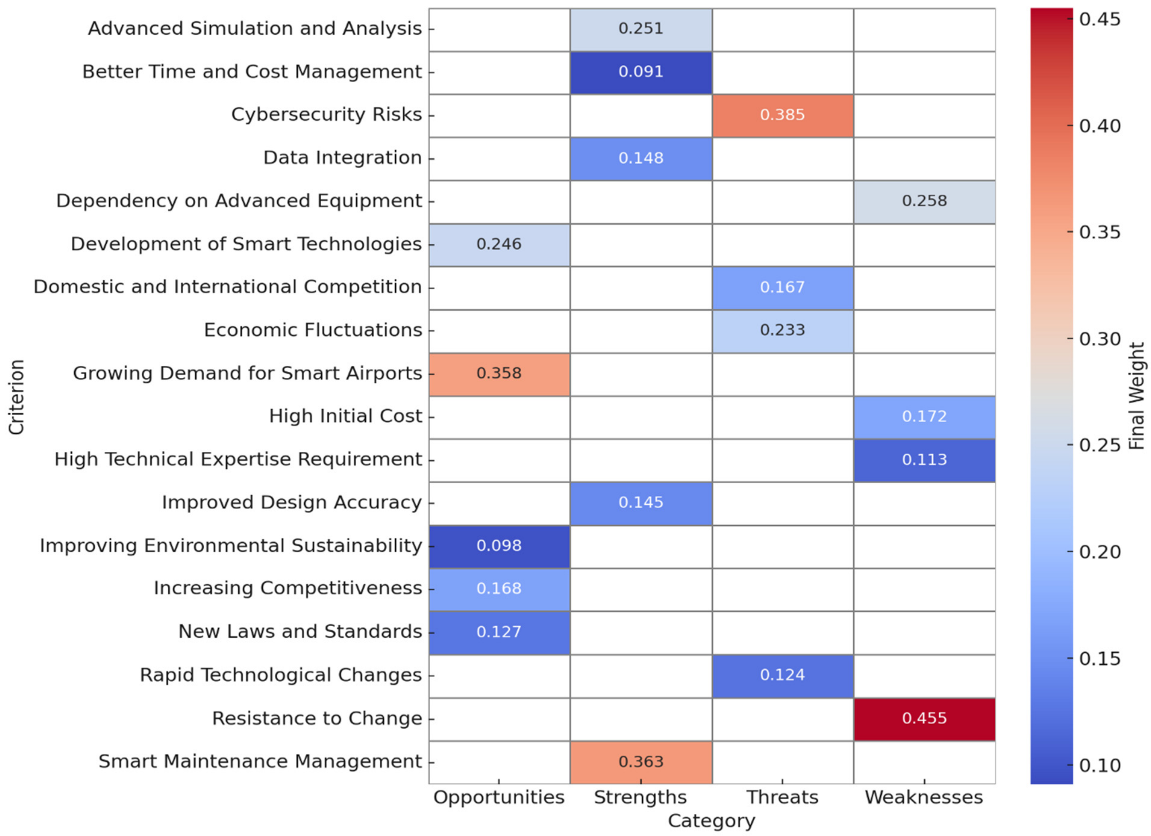

Figure 7. Weighting criteria based on category (Authors).

The sensitivity analysis chart for all criteria across categories (strengths, weaknesses, opportunities, and threats) illustrates how weight changes affected each criterion's value and ranking. The chart compares original weights (blue columns), 10% reduced weights (green columns), and 10% increased weights (red columns).

Initially, categories with high weights, such as smart maintenance management in strengths, resistance to change in weaknesses, growing demand for smart airports in opportunities, and cyber dangers in threats, continued to rank at the top even after a 10% weight adjustment. Critical decisions should emphasize these aspects since they influence whether a strategy succeeds or fails.

Criteria with medium weights, such as increased competitiveness in opportunities and internal and external competition in threats, responded more sensitively to weight changes. Adjusting the weights can shift these criteria's relative positions in the ranking; therefore, they should be carefully considered when designing.

Elements with lower weights, such as improving environmental sustainability in opportunities or non-compliance with local laws in threats, changed less when shifting weights. These elements, however, should not be ignored entirely due to their indirect and long-term consequences, as they can play an essential role in some cases.

The sensitivity study verified the weight model's stability, as key criteria rankings stayed consistent even with ±10% weight variances. This characteristic ensures that approaches based on this model are reliable, even in the presence of uncertainty. High-weighted criteria should precede planning and resource allocation, whereas medium-weighted and low-weighted criteria should complement the primary approach.

Figure 8 displays the distribution of criteria weights based on the SWOT (strengths, weaknesses, opportunities, and threats) category and highlights the range of variation for each criterion.

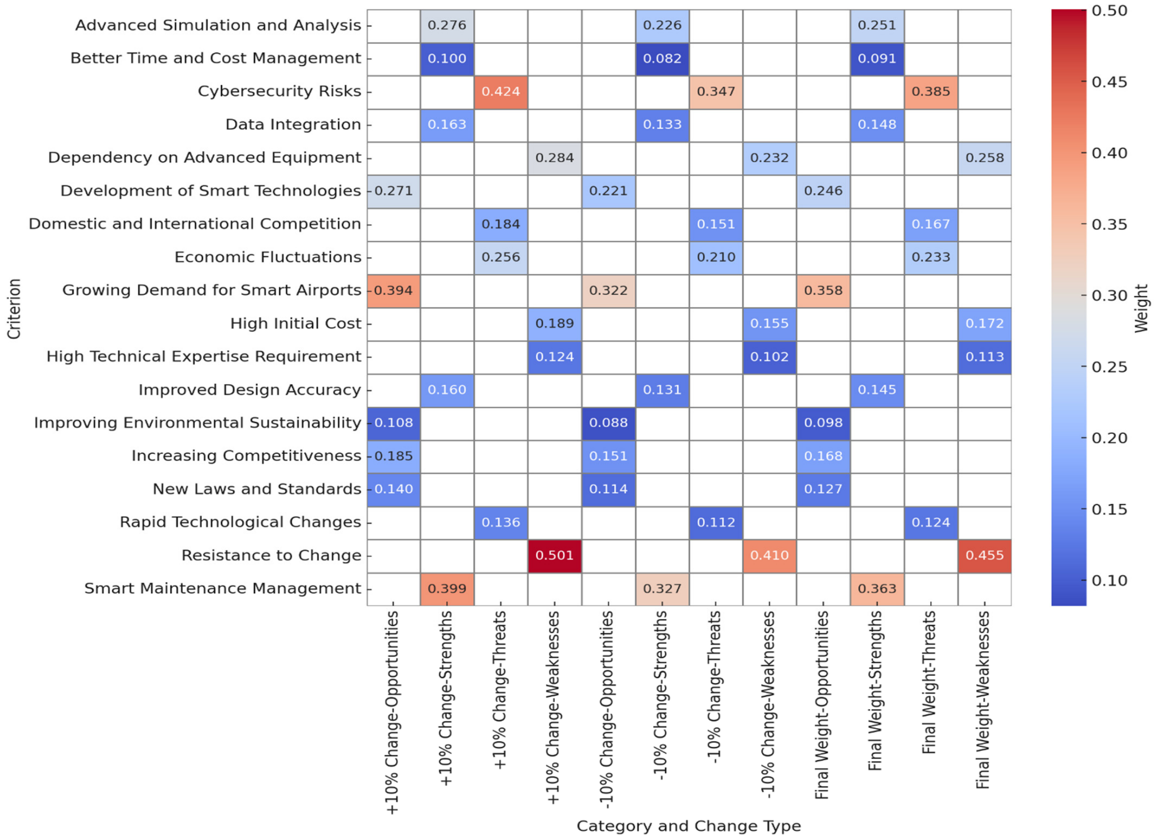

Figure 8. SWOT sensitivity analysis of all criteria (Authors).

Figure 9 illustrates the correlation of relationships between SWOT categories (strengths, weaknesses, opportunities, and threats) and indicates whether they were positively or negatively associated, depending on the correlation value (1.00: perfect positive correlation (like strengths with itself), values close to 1: strong positive correlation, values close to 0: no correlation, and values close to –1: strong negative correlation).

The correlation visualization vividly illustrated the relationships between the SWOT categories. The strong positive connection between strengths and flaws suggests that the organization may leverage its strengths to manage and mitigate flaws. There was also a considerable positive link between opportunities and strengths, implying that the organization can capitalize on opportunities by using existing strengths. On the other hand, the limited association between threats and other categories implies that dealing with threats necessitates autonomous solutions and that strengths or opportunities have less influence on managing these threats.

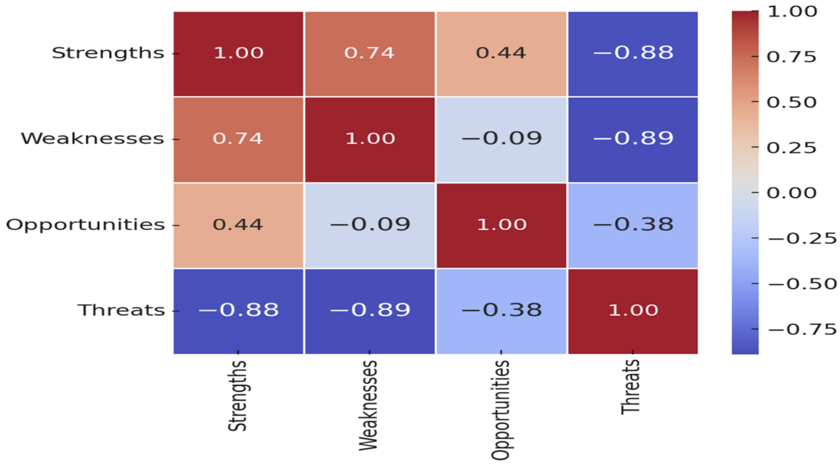

Figure 9. SWOT categories (Authors).

The moderate link between opportunities and flaws suggests that opportunities can be essential in mitigating the organization's flaws, but this relationship is insufficient and requires more attention. The absence of a negative correlation in this research implies that the impact of any of these categories does not function in reverse, and each can contribute to increasing the organization's performance simultaneously. This research demonstrated that the company should leverage its strengths to capitalize on opportunities and manage weaknesses, while addressing risks separately.

5. Conclusions

Airport building management necessitates innovative and integrated approaches because of the complexity of infrastructure, the diversity of stakeholders, and the need for safety. Based on SWOT analysis and the AHP technique, using BIM as an advanced tool provides numerous benefits for increasing productivity, lowering costs, and improving service quality. By producing accurate and connected information models, BIM reduces design errors and improves time and cost management. According to the findings, smart maintenance management (0.364) and enhanced simulation and analysis (0.251) were two of BIM's most significant assets in airport building management. Focusing on these factors can result in better efficiency and fewer issues caused by the complexity of airport infrastructure. These advantages demonstrate that with the effective use of BIM technologies, improving performance in airport project management is possible.

Despite BIM's benefits, its application presents obstacles. Key problems included resistance to change (0.456), significant initial costs (0.172), and a high level of technical skill (0.113). Organizations and people may be resistant to adopting new technologies and processes. Furthermore, the initial expenses and the need for technical competence are significant impediments to the general adoption of this technology. Support programs, specific training, and organizational culture are required to overcome these obstacles.

Along with these problems, numerous opportunities exist for improving and expanding BIM in airport building management. The growing demand for smart airports (0.358) and the development of smart technologies (0.247) imply that this industry needs more innovation and advanced technology. Exploiting these opportunities can lead to long-term competitive advantages and a major improvement in service quality.

External dangers have a crucial role in the successful deployment of BIM. Cyber risks (0.386) and economic fluctuations (0.233) were the most significant hazards. Information security and digital infrastructure are in danger, and economic changes can negatively impact project timelines and scope. Dealing with these challenges necessitates careful preparation and implementing adaptable management strategies. Employing BIM to manage airport buildings, using strengths such as smart maintenance management and advanced simulation, and capitalizing on possibilities such as the growing need for smart airports, can increase process efficiency and productivity. To attain these objectives, addressing weaknesses, such as early costs and resistance to change, is critical, as well as managing dangers, such as cyber hazards and economic volatility. Investing in specialist training, sustainable solutions, and cross-sector collaboration can provide a complete and efficient strategy for managing complex airport infrastructure. These approaches and the focus on key criteria will pave the road for airport growth and performance enhancement.

To implement BIM in airport construction management, it is necessary to design a step-by-step framework. In the first step, the organization should assess its readiness to adopt this technology, including reviewing the existing infrastructure and resources. Then, in the second step, the necessary training is provided to the expert staff to familiarize themselves with BIM software and technologies. The third step is gradually implementing BIM in smaller projects to identify and solve initial problems. Finally, in the fourth step, continuous monitoring and evaluation are carried out to improve and refine the processes. Challenges such as resistance to change, high initial costs, and the need for specialized skills may slow the adoption process. Organizations must have appropriate training strategies, organizational support, and culture-building to overcome these obstacles. Also, to deal with external threats, such as cyber risks and economic fluctuations, solutions such as Blockchain should be used to enhance security and reduce risks. This comprehensive approach can lead to improved efficiency and productivity in airport infrastructure management and, in the long term, enhance the performance of airport projects.

To implement building information modeling, we have developed a framework that includes five key steps for airport facility management. Figure 10 illustrates that BIM in smart airport management is a continuous process that includes needs analysis, modeling, integration, data analysis, and strategic decision-making. By combining BIM with modern technologies, like the Internet of Things (IoT), artificial intelligence (AI), and Geographic Information Systems (GIS), operational efficiency may be boosted, while expenses are decreased.

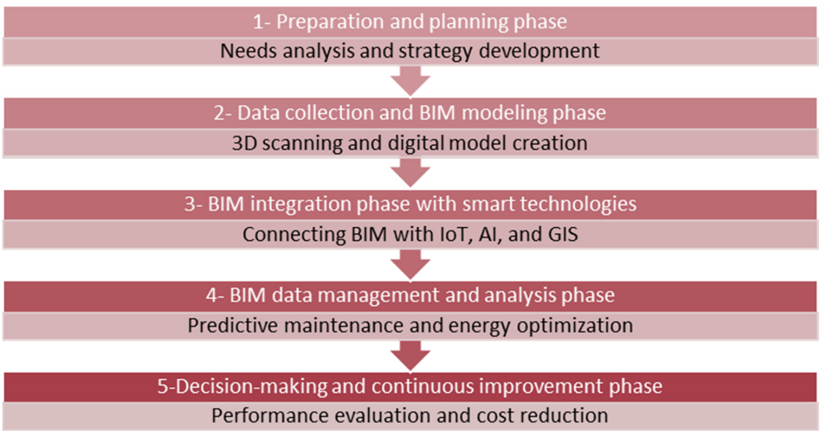

Figure 10. Steps to implementing building information modeling at airports (Authors).

Keskin and Salman [56] also suggested a design framework for using BIM in airports. There are differences between their work and the current research. Keskin and Salman's [56] research used performance indicators to optimize operations and emphasized stakeholder collaboration and data transfer processes. However, this study used a more operational BIM implementation focused on predictive maintenance and airport performance optimization.

For future research, it is important to explore the development of strategies to mitigate these challenges, such as combining Blockchain and BIM to enhance cybersecurity and examining the adoption of BIM in the long term. Future studies could also examine the scalability of BIM across different airport sizes and regions or investigate BIM to contribute to sustainable and green airport operations.

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Appendix A

Table A1. Strengths.

	Project Information Integration	Increased Design Accuracy	Improved Time and Cost Management	Advanced Simulation and Analysis	Smart Maintenance Management
Project Information Integration	1				
Increased Design Accuracy		1			
Improved Time and Cost Management			1		
Advanced Simulation and Analysis				1	
Smart Maintenance Management					1

Table A2. Weaknesses.

	High Initial Cost	High Technical Expertise Required	Resistance to Change	Dependence on Advanced Equipment
High Initial Cost	1			
High Technical Expertise Required		1		
Resistance to Change			1	
Dependence on Advanced Equipment				1

Table A3. Opportunities.

	Development of Smart Technologies	Growing Demand for Smart Airports	New Rules and Standards	Increased Competitiveness	Improved Environmental Sustainability
Development of Smart Technologies	1				
Growing Demand for Smart Airports		1			

Table A3. *Cont.*

	Development of Smart Technologies	Growing Demand for Smart Airports	New Rules and Standards	Increased Competitiveness	Improved Environmental Sustainability
New Rules and Standards			1		
Increased Competitiveness				1	
Improved Environmental Sustainability					1

Table A4. Threats.

	Economic Fluctuations	Non-Compliance with Local Laws	Domestic and Foreign Competition	Cyber Risks	Rapid Technological Changes
Economic Fluctuations	1				
Non-Compliance with Local Laws		1			
Domestic and Foreign Competition			1		
Cyber Risks				1	
Rapid Technological Changes					1

References

1. Kacar, B.; Turhan, E.; Dalkiran, A.; Karakoc, T.H. Green Airport building certification comparison: A practical approach for Airport Management. *Int. J. Green Energy* **2023**, *20*, 602–615. [CrossRef]
2. Sun, J.; Oh, E.; Chai, G.; Ma, Z.; Ong, D.E.; Bell, P. A systematic review of structural design methods and nondestructive tests for airport pavements. *Constr. Build. Mater.* **2024**, *411*, 134543. [CrossRef]
3. Karamoozian, M.; Zhang, H. Obstacles to green building accreditation during operating phases: Identifying challenges and solutions for sustainable development. *J. Asian Archit. Build. Eng.* **2025**, *24*, 350–366. [CrossRef]
4. Brady, T.; Davies, A. Learning to deliver a mega-project: The case of Heathrow Terminal 5. In *Procuring Complex Performance*; Routledge: London, UK, 2010; pp. 190–212.
5. Crichton, G. Learning from history: The Glasgow Airport terrorist attack. *J. Bus. Contin. Emerg. Plan.* **2014**, *8*, 169–180. [CrossRef]
6. Camastral, M.; Barnes, P. Risk-informed thinking in airports: The application of business continuity management in airport infrastructure. In Proceedings of the 15th Annual Conference of the International Research Society for Public Management, Aguascalientes, Mexico, 18–21 June 2011.
7. Alvarez, A.P.; Ordieres-Meré, J.; Loreiro, Á.P.; de Marcos, L. Opportunities in airport pavement management: Integration of BIM, the IoT and DLT. *J. Air Transp. Manag.* **2021**, *90*, 101941. [CrossRef]
8. Sarvari, H.; Chen, Z.; Chan, D.W.; Lester, E.A.; Yahaya, N.; Nassereddine, H.; Lotfata, A. A global survey of infection control and mitigation measures for combating the transmission of COVID-19 pandemic in buildings under facilities management services. *Front. Built Environ.* **2022**, *7*, 644104. [CrossRef]
9. Vaghefi-Rezaee, H.A.; Khademi-Adel, S.; Sarvari, H.; Edwards, D.J.; Rashidi, A. A hybrid risk-based maintenance approach for evaluating the maintenance risks of urban tunnel lighting systems. *J. Qual. Maint. Eng.* **2025**, *31*, 83–104. [CrossRef]
10. Lee, J.Y.; Irisboev, I.O.; Ryu, Y.S. Literature review on digitalization in facilities management and facilities management performance measurement: Contribution of industry 4.0 in the global era. *Sustainability* **2021**, *13*, 13432. [CrossRef]
11. Javaherikhah, A.; Lopez, M.V.; Sarvari, H. Assessing the Efficiency of Integrating BIM and Blockchain to Improve Information Management for Mars Buildings: A SWOT-AHP Analysis. *Buildings* **2025**, *15*, 494. [CrossRef]
12. Javaherikhah, A.; Valiente Lopez, M. Effective Factors for Implementing Building Information Modeling Using Fuzzy Method to Manage Buildings on Mars. *Buildings* **2023**, *13*, 2991. [CrossRef]
13. Liu, R. Comparative analysis of critical factors for BIM adoption in airport. *Theor. Nat. Sci.* **2023**, *19*, 265–274. [CrossRef]
14. Sarvari, H.; Chan, D.W.M.; Rakhshanifar, M.; Banaitiene, N.; Banaitis, A. Evaluating the impact of building information modeling (BIM) on mass house building projects. *Buildings* **2020**, *10*, 35. [CrossRef]
15. Asgari Siahboomy, M.; Sarvari, H.; Chan, D.W.; Nassereddine, H.; Chen, Z. A multi-criteria optimization study for locating industrial warehouses with the integration of BIM and GIS data. *Archit. Eng. Des. Manag.* **2021**, *17*, 478–495. [CrossRef]

16. Javaherikhah, A. Technology and Nanotechnology in Smart Buildings. In Proceedings of the 7th International Conference on Technological Innovation in Building, Madrid, Spain, 23 March 2022. [CrossRef]
17. Khoshfetrat, R.; Sarvari, H.; Chan, D.W.; Rakhshanifar, M. Critical risk factors for implementing building information modelling (BIM): A Delphi-based survey. *Int. J. Constr. Manag.* **2022**, *22*, 2375–2384. [CrossRef]
18. Javaherikhah, A.; Valiente Lopez, M.; Mohandes, S.R. Developing an Inspector-Centric Blockchain-Enabled Conceptual Framework for BIM Management in Mars Buildings. *Buildings* **2023**, *13*, 2858. [CrossRef]
19. Chan DW, M.; Sadeq, D.A.; Sarvari, H.; Edwards, D.J.; Parsaei, A.; Javaherikhah, A. Determining the Essential Criteria for Choosing Appropriate Methods for Maintenance and Repair of Iraqi Healthcare Building Facilities. *Buildings* **2023**, *13*, 1629. [CrossRef]
20. Zhou, C.; Yan, J. *BIM and IoT Integration Applied in Airport Infrastructure Construction*; SPIE: Bellingham, WA, USA, 2022; Volume 12165, pp. 67–73. [CrossRef]
21. Huang, E.; Zhang, S.; Xie, Y. Research on Forward Design Method for Airport Pavements Based on BIM Technology. In Proceedings of the 2024 IEEE 10th International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications (MAPE), Guangzhou, China, 27–30 November 2024; pp. 1–4.
22. Dalkiran, A.; Sogut, M.Z.; Karakoc, T.H. Life Cycle Assessment (LCA) Applications in Airports. In *Life Cycle Assessment in Aviation: Theory and Applications*; Springer: Berlin/Heidelberg, Germany, 2024; pp. 63–92.
23. Wijeratne, P.U.; Gunarathna, C.; Yang, R.J.; Wu, P.; Hampson, K.; Shemery, A. BIM enabler for facilities management: A review of 33 cases. *Int. J. Constr. Manag.* **2024**, *24*, 251–260. [CrossRef]
24. Wang, B. Intelligent Control Method for Airport Road Construction Project Progress Based on BIM. In Proceedings of the 2024 3rd International Conference on Energy and Power Engineering, Control Engineering (EPECE), Chengdu, China, 23–25 February 2024; pp. 170–173.
25. Koseoglu, O.; Keskin, B.; Ozorhon, B. Challenges and enablers in BIM-enabled digital transformation in mega projects: The Istanbul new airport project case study. *Buildings* **2019**, *9*, 115. [CrossRef]
26. Altohami, A.; Haron, N.; Law, T. Investigating Approaches of Integrating BIM, IoT, and Facility Management for Renovating Existing Buildings: A Review. *Sustainability* **2021**, *13*, 3930. [CrossRef]
27. Guedes, Í.; Andrade, M.; Carvalho, A. BIM-based airport design project standardization (IFC) for use of code checking. In *Formal Methods in Architecture, Proceedings of the 5th International Symposium on Formal Methods in Architecture (5FMA), Lisbon 2020*; Springer: Berlin/Heidelberg, Germany, 2021; pp. 37–47.
28. Yang, C.; Mao, L. Analysis on risk factors of BIM application in construction project operation and maintenance phase. *J. Serv. Sci. Manag.* **2021**, *14*, 213. [CrossRef]
29. Lahna, T. The Use of BIM for the Management of Predictive Maintenance in Airport Infrastructure. Ph.D. Thesis, Institut National Polytechnique de Toulouse-INPT, Toulouse, France, 2023.
30. Haribowo, D.; Utama, A.A. A Proposed Design of Knowledge Based Performance Management System for Airport Company. *Co-Value J. Ekon. Kop. Dan Kewirausahaan* **2024**, *15*. [CrossRef]
31. Chang, Y.-H.; Shao, P.-C.; Chen, H.J. Performance evaluation of airport safety management systems in Taiwan. *Saf. Sci.* **2015**, *75*, 72–86. [CrossRef]
32. Adebiyi, K.A.; Akinyemi, O.O.; Adeleye, E.O. Multi-criteria performance evaluation of an airline maintenance programme-a case study. *Afr. J. Sci. Technol. Innov. Dev.* **2016**, *8*, 79–87. [CrossRef]
33. Merhej, T.; Feng, D.C. Parameter sensitivity analysis of airport rigid pavement thickness using FAARFIELD program. *Adv. Mater. Res.* **2011**, *243*, 4068–4074. [CrossRef]
34. Gheni Hussien, I.; Saeed Rasheed, Z.; Asaadsamani, P.; Sarvari, H. Perceived Critical Success Factors for Implementing Building Information Modelling in Construction Small- and Medium-Sized Enterprises. *CivilEng* **2025**, *6*, 5. [CrossRef]
35. Zhang, N.; Zhu, J.F. Fuzzy analytic hierarchy process method for civil aviation airport security information management. *Appl. Mech. Mater.* **2015**, *701*, 40–43. [CrossRef]
36. Alansari, Z.; Soomro, S.; Belgaum, M.R. Smart airports: Review and open research issues. In *Emerging Technologies in Computing: Second International Conference, iCETiC 2019, Proceedings 2, London, UK, 19–20 August 2019*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 136–148.
37. Yu, G.; Zhang, X.; Dong, Z.; Lu, B. Evaluation of Flight Procedure Based on QAR Data: A Case Study on Daocheng Yading Airport. In Proceedings of the 2023 IEEE 5th International Conference on Civil Aviation Safety and Information Technology (ICCASIT), Dali, China, 1–13 October 2023; pp. 494–500.
38. Rezaee, M.J.; Yousefi, S. An intelligent decision making approach for identifying and analyzing airport risks. *J. Air Transp. Manag.* **2018**, *68*, 14–27. [CrossRef]
39. Rashidian, S.; Drogemuller, R.; Omrani, S. Building information modelling, integrated project delivery, and lean construction maturity attributes: A Delphi study. *Buildings* **2023**, *13*, 281. [CrossRef]

40. Alhammad, M.; Eames, M.; Vinai, R. Enhancing Building Energy Efficiency through Building Information Modeling (BIM) and Building Energy Modeling (BEM) Integration: A Systematic Review. *Buildings* **2024**, *14*, 581. [CrossRef]
41. Adeyemi, A.B.; Ohakawa, T.C.; Okwandu, A.C.; Iwuanyanwu, O.; Ifechukwu, G.-O. Advanced Building Information Modeling (BIM) for affordable housing projects: Enhancing design efficiency and cost management. *J. Build. Inf. Model.* **2024**, *12*, 45–60.
42. Ehab, A.; Mahdi, M.A.; El-Helloty, A. BIM Maintenance System with IoT Integration: Enhancing Building Performance and Facility Management. *Civ. Eng. J.* **2024**, *10*, 1953–1973. [CrossRef]
43. Lee, J.; Yang, H.; Lim, J.; Hong, T.; Kim, J.; Jeong, K. BIM-based preliminary estimation method considering the life cycle cost for decision-making in the early design phase. *J. Asian Archit. Build. Eng.* **2020**, *19*, 384–399. [CrossRef]
44. Saka, A.B.; Chan, D.W. Knowledge, skills and functionalities requirements for quantity surveyors in building information modelling (BIM) work environment: An international Delphi study. *Archit. Eng. Des. Manag.* **2020**, *16*, 227–246. [CrossRef]
45. Ahmed, S. Barriers to implementation of building information modeling (BIM) to the construction industry: A review. *J. Civ. Eng. Constr.* **2018**, *7*, 107–113. [CrossRef]
46. Gao, X.; Pishdad-Bozorgi, P. BIM-enabled facilities operation and maintenance: A review. *Adv. Eng. Inform.* **2019**, *39*, 227–247. [CrossRef]
47. Yang, A.; Han, M.; Zeng, Q.; Sun, Y. Adopting building information modeling (BIM) for the development of smart buildings: A review of enabling applications and challenges. *Adv. Civ. Eng.* **2021**, *2021*, 8811476. [CrossRef]
48. Lee, Y.-C.; Eastman, C.M.; Solihin, W. Rules and validation processes for interoperable BIM data exchange. *J. Comput. Des. Eng.* **2021**, *8*, 97–114. [CrossRef]
49. Cao, D.; Li, H.; Wang, G.; Luo, X.; Tan, D. Relationship network structure and organizational competitiveness: Evidence from BIM implementation practices in the construction industry. *J. Manag. Eng.* **2018**, *34*, 04018005. [CrossRef]
50. Carvalho, J.P.; Bragança, L.; Mateus, R. Optimising building sustainability assessment using BIM. *Autom. Constr.* **2019**, *102*, 170–182. [CrossRef]
51. Wu, W.; Wang, J.; Zhang, Y. Application of BIM in Airport Reconstruction Projects. *J. Civ. Eng. Urban Plan.* **2024**, *6*, 98–103.[CrossRef]
52. Abdelalim, A.M.; Elbeltagi, E.E.; Abdelgawad, M. Automated detection of building rules compliance using building information modelling. *Int. J. Appl. Manag. Sci.* **2024**, *16*, 138–173. [CrossRef]
53. Wang, Y.; Zhao, B.; Nie, Y.; Jiang, L.; Zhang, X. Challenge for Chinese BIM Software Extension Comparison with International BIM Development. *Buildings* **2024**, *14*, 2239. [CrossRef]
54. Ghadiminia, N.; Mayouf, M.; Cox, S.; Krasniewicz, J. BIM-enabled facilities management (FM): A scrutiny of risks resulting from cyber-attacks. *J. Facil. Manag.* **2022**, *20*, 326–349. [CrossRef]
55. Krasovskaya, O.A.; Vyaznikov, V.E.; Mamaeva, A.I. Application of BIM technologies as it projects for digital transformation in industry. In *International Scientific and Practical Conference Digital and Information Technologies in Economics and Management*; Springer: Berlin/Heidelberg, Germany, 2021; pp. 104–116.
56. Keskin, B.; Salman, B. Building Information Modeling Implementation Framework for Smart Airport Life Cycle Management. *Transp. Res. Rec.* **2020**, *2674*, 98–112. [CrossRef]