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Assessing the Efficiency of Integrating BIM and Blockchain to Improve Information Management for Mars Buildings: A SWOT-AHP Analysis

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Abstract: This research investigates integrating Building Information Modeling (BIM) and blockchain technology to enhance building information's security, reliability, and accuracy in Martian environments. Given the unique challenges posed by extraterrestrial construction, this study evaluates the feasibility of this hybrid approach through a structured SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis. Expert inputs were collected through a comprehensive questionnaire identifying nine strengths, eight weaknesses, eight opportunities, and six threats to implementing BIM and blockchain technology in space projects. The Analytical Hierarchy Process (AHP) was used to prioritize these factors. Findings indicate that the strengths are cost calculation and budgeting (26.21), and the weaknesses are technology complexity (25.488). Increased productivity (19.16) is the most important criterion at the opportunity point, and defects in data security (20.68) are the most important at the threat point. The SWOT analysis places BIM and blockchain integration in a conservative strategy quadrant, indicating that the technology holds significant promise but requires further development and refinement. Ultimately, this research contributes to the growing knowledge about extraterrestrial construction technologies and provides a foundation for developing flexible and autonomous building systems for Martian habitats.

Keywords: BIM; blockchain; Mars buildings; life on Mars; BMS

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1. Introduction

Mars, Earth's nearest neighbor and one of the most appealing targets for space travel, has long fascinated scientists and engineers. With technological advancements and a rise in space data, the question becomes whether people can one day inhabit Mars and how this process can be controlled. The importance of designing and building sustainable and efficient dwellings on Mars is acute [1]. Given the specific challenges of inhabiting Mars, such as soil toxicity, intense radiation, and low gravity, it is essential to create infrastructure suitable for human life. One of the new solutions for managing information and construction processes on this planet is using advanced technologies such as Building Information Modeling (BIM) and blockchain [2]. BIM allows engineers to accurately and efficiently carry out the necessary designs and plans. At the same time, blockchain, as a secure system for recording and managing information, provides the necessary transparency and security [3]. Together, these two technologies can provide a comprehensive solution for controlling the information management of Martian buildings. Using BIM, engineers can simulate and analyze projects and, with the help of blockchain, store all construction data and documentation in an immutable and accessible form for all stakeholders [4]. This combination helps optimize construction processes and allows for more precise tracking and control of resources and materials [5]. However, the important point is, what should be considered when building Martian buildings on this planet?

Figure 1 shows a proposed human habitat on the surface of Mars. The structure consists of hexagonal sections with solar panels on the roof that generate electricity for internal systems. Several units in the image are connected, and their interior rooms are designed for habitation and research.

Figure 1. Martian building (Source: Authors).

Martian buildings possess qualities such as safety, efficiency, expandability, temperature, gravity, protection against radiation, solar wind, cosmic rays, and solar flares. Safety is paramount in the design of Martian habitats. This requires incorporating multiple levels of redundancy into each system. For example, habitats should be divided into interconnected, pressurized compartments. In the event of an emergency, such as a fire or loss of pressure, each compartment should have at least two exit routes. The design should also ensure that the failure of one unit does not isolate other functional areas [6]. Efficiency is crucial given Mars' distance from Earth and its limited resources. The design should minimize energy consumption and labor requirements while maximizing efficiency. This means using materials and systems that are effective and sustainable in the Martian environment [7]. The colony design should allow for easy expansion without compromising the integrity or quality of existing structures. A modular approach can facilitate this, allowing for the addition of additional units as needed [6]. Habitability is also perhaps the most challenging aspect to measure, but it is essential for the mental health of the residents. Factors such as natural light and views are very important; therefore, incorporating windows presents engineering challenges but is necessary to create comfortable living spaces. Attention to social dynamics and psychological needs will also play a vital role in ensuring the success of a colony [8,9]. However, engineering challenges include Mars's average surface temperature is about −60 degrees Celsius, which is associated with significant temperature changes during the day and night. This requires tight insulation and temperature regulation systems to prevent structural stresses [1,10,11]. With only 38% of Earth's gravity (roughly 3.7 m/s^2), the main structural concern shifts from supporting buildings against gravity to ensuring they stay connected to the Earth. This requires innovative engineering solutions for wind loads and other forces [12,13]. Mars has a weak magnetic field and a thin atmosphere that exposes the inhabitants to different types of radiation [14]. Charged particles emitted by the Sun can be reduced by covering living spaces with about 1 m of Martian soil (regolith) [15]. Furthermore, Cosmic rays are more challenging but can be somewhat shielded using regolith [16]. Moreover, solar flare events are more difficult but predictable. Residents can prepare for these events by receiving adequate warnings before solar flares [17,18]. Despite Mars's thin atmosphere, this planet has a dynamic climate. One important phenomenon is the seasonal dust storms that can cover the entire planet. These storms occur when winds lift very small dust particles from the Earth's surface and carry them up to 100 km per hour. Finally, human habitation on Mars requires precise, safe, and efficient habitat design. Technologies such as BIM and blockchain make it possible to optimize construction processes and manage the specific challenges of living on this planet. These approaches help create sustainable infrastructure and make it possible to realize the dream of living on Mars.

Upon studying the research literature, the following question emerges: Given the conditions of Mars and the advancements in science and technology, is the integration of BIM with blockchain a viable alternative for managing and regulating the information of Martian structures? In this vein, this research seeks to assess the feasibility and dependability of integrating BIM and blockchain for improving information management for Mars buildings. In this regard, a combined SWOT and AHP methods was used to identify and assess the related criteria. The findings of this research elucidate interplanetary construction technologies, aiding policymakers in making informed decisions on the development of flexible and autonomous building systems for Martian habitats.

2. Research Background

Research has stated [5,19,20] that the use of BIM and its integration with blockchain can lead to accurate modeling of building dimensions, accuracy of information, and assurance of construction instructions. Also, blockchain can ensure accurate assurance of resources and materials used in the building and high accuracy of data and information. It can help better manage data and build with continuous data monitoring.

Also, Reference [21] has stated that using BIM and blockchain significantly impacts cost calculation and budgeting, and they can be managed well until the project is presented. The research [22] also states that the construction industry lacks a comprehensive and general plan for the use and management of BIM in the entire life cycle of the building [23], especially the use of BIM technology for asset management and facility management. BIM integration with blockchain can be considered a reliable solution for building and project management. However, integrating BIM with blockchain can improve quality and safety, high accuracy in data and information, better cooperation between teams, and better management of building information, such as resource and material management [24]. However, among the things that can be considered in the context of implementing BIM integration with blockchain is that its implementation has technological complications and requires initial costs [25].

According to experts' opinions, there is always resistance to change in scientific societies [26]. Other problems on Mars include the lack of basic infrastructure for building and transferring technology. Also, the conditions of Mars are another issue that should be considered in the construction and transfer of technology to Mars [1]. Considering Mars's conditions, the technology's stability, and its distance from Earth, the time-consuming implementation is another problem on the way to transferring to Mars [27–29].

On the other hand, using BIM and its integration with blockchain can lead to innovation in construction and the creation of smart buildings [30]. Also, these innovations and the use of smart buildings lead to sustainable development [31]. Also, with the use of the Internet of Things and smart buildings, productivity has increased, transparency in information has been created, and risks can be predicted and managed [32]. However, using BIM and its integration with blockchain leads to better project management and improved coordination, leading to technological advances in this industry [33].

Traveling to Mars has high technical risks because it is an almost unknown environment for humans and difficult environmental conditions [34,35]. According to this point, blockchain is highly secure. Still, it is important to note that a solution to its security flaws has not yet been found, and it is not yet known whether this security will continue to be maintained. Therefore, if this security is breached, data security will suffer, and, as mentioned, there is no certainty of the future [36].

From the review of the research conducted and other existing research conducted in the field of integrating BIM with blockchain, none of them have examined the implementation method or the strengths and weaknesses of implementing this technology in sensitive buildings such as nuclear and military buildings or on Mars, which can support the necessity of conducting this research.

According to the research, issues such as accurate modeling of manufacturing instructions, resource, and material management, cost calculation and budgeting, project management, quality and safety improvement, high data accuracy, data management, cooperation between teams, and continuous monitoring can be identified as strong points. The complexity of technology, initial costs, resistance to change, limited infrastructure, legal problems, time-consuming implementation, sustainability of technology, and problems of adaptation to Mars conditions. As examples of weaknesses, innovation in manufacturing, sustainable development, increased productivity, transparency in information, forecasting and risk management, better project management, technological developments, and improvement of technologies are examples of opportunities, and finally, technical risks, flaws in data security, difficult environmental conditions, international competition, uncertainty about the future and the need for training and skills are included in the research as threats for analysis. Table 1 shows all the criteria and related explanations in detail in four main categories: strengths, weaknesses, opportunities, and threats.

Table 1. All criteria in SWOT with description.

SWOT	Criteria	Description	Source/s
Strength	Detailed modeling and construction instructions	BIM provides comprehensive 3D models and instructions, which are critical for the great precision required in Mars building.	[2,37]
	Management of resources and materials	Blockchain allows for transparent and verifiable resource management, while BIM optimizes material consumption, which is crucial given Mars' limited resources.	[38–40]
	Cost calculation and budgeting	Combining BIM cost estimation with blockchain-safe transactions improves financial planning for Mars projects.	[41,42]
	Project management	BIM simplifies scheduling and tracking, while blockchain enables safe communication and data sharing between stakeholders.	[43,44]
	Improve quality and safety	BIM simulations and blockchain's tamper-proof records help to improve safety and quality standards in Mars construction projects.	[19,45]
	High precision	Both technologies ensure high precision in design, execution, and record-keeping, vital for Mars's unique conditions.	[46,47]
	Data management	BIM centralizes data, while blockchain secures and verifies it, resulting in better overall information management.	[48,49]
	Collaboration between teams	The integration facilitates real-time collaboration through BIM and ensures trust and accountability via blockchain.	[50,51]

Table 1. *Cont.*

SWOT	Criteria	Description	Source/s
Strength	Continuous monitoring	Continuous upgrades to BIM models and immutable information in blockchain enable effective progress tracking.	[52,53]
Weakness	Complexity of technology	Both technologies are complex and require specialized expertise, especially when adapted for extraterrestrial applications.	[54,55]
	Initial costs	The integration involves significant upfront investment in software, hardware, and training.	[56,57]
	Resistance to change	Adopting advanced technologies like BIM and blockchain may face resistance.	[58–60]
	Limited infrastructure	Mars's lack of infrastructure makes the efficiency of BIM and blockchain critical to reducing reliance on physical resources.	[61,62]
	Legal problems	Establishing legal frameworks for smart contracts and Blockchain-based transactions may be challenging in a Mars context.	[63,64]
	Time-consuming implementation	Implementing and integrating these technologies requires time, possibly delaying the construction schedule.	[65,66]
	Sustainability of technology	Both technologies are designed for long-term usage, ensuring sustainability in managing Martian construction projects.	[67]
	Problems of compatibility with Mars	Modifications in BIM and blockchain systems are necessary to handle Mars.	[4,68]
Opportunity	Innovation in construction	Integrating BIM and blockchain exemplifies innovation, enabling futuristic construction methods suitable for Mars.	[4,69]
	Sustainable development	These technologies help minimize waste and optimize resource usage, supporting sustainable Martian habitats.	[70–72]
	Increase productivity	Automation and data integrity from BIM and blockchain significantly boost productivity in harsh Mars conditions.	[73,74]
	Transparency in information	Blockchain ensures data transparency, and BIM facilitates clear visualization of all project stages.	[75,76]
	Risk prediction and management	BIM's simulations and blockchain's secure data storage allow for effective risk analysis and mitigation.	[77,78]
	Better project management	BIM and blockchain enhance coordination, communication, and accountability in project execution.	[79,80]
	Technological advances	The integration showcases cutting-edge technological applications tailored for extraterrestrial construction.	[81,82]
	Improve coordination	Real-time BIM updates and blockchain's shared ledger ensure seamless coordination among teams.	[83,84]
Threat	Technical risks	Dependency on advanced technology may lead to failures if systems are not adequately adapted for Mars.	[85,86]
	Defects in data security	Blockchain protects against data breaches, addressing potential risks in sensitive Mars projects.	[87,88]
	Difficult environmental conditions	BIM helps model and simulate environmental challenges, while Blockchain secures data exchange in these extreme conditions.	[89,90]
	International competition	Efficient integration of BIM and blockchain can provide a competitive edge in global efforts to build on Mars.	[91,92]
	Uncertainty about the future	Both technologies offer adaptability and resilience, mitigating uncertainties in Mars-based construction projects.	[93,94]
	Need for training and skills	Specialized training for integrating BIM and blockchain ensures teams are prepared to handle the challenges of Mars construction.	[50,91]

3. Research Method

The method of this research is part of applied research in terms of its purpose, in terms of thematic features of descriptive research; in terms of the time of data collection, it is part of survey research; and in terms of the method of data collection, it is part of field research. The statistical population is everything that has the conditions to enter the research, which, in this study, constitutes the population that researchers have tried in the field of research and development of Mars. Considering that the nature of the current research is expert, and in expert research, such as SWOT, AHP, etc., the opinions have a suitable convergence and high accuracy; the community is around 5 to 20 people. According to the same issue, 10 experts will be helped to collect data in this research, and the required questionnaires will be distributed among these experts.

Figure 2 shows the flow chart of the research process. The flowchart begins with the “Start” stage, followed by the “Research Similarities” stage, which involves a thorough analysis of previous studies to provide context for the current research. The second stage, “Extract Four Criteria from Research History”, involves identifying and categorizing the important aspects of the SWOT framework: strengths, weaknesses, opportunities, and threats. The collected criteria are then ranked across the four SWOT domains using the Analytic Hierarchy Process (AHP) to assess their relevance. After ranking, the process moves on to “Perform SWOT Analysis to Find Research Areas”, where the data are reviewed to identify areas that require improvement or additional research. The penultimate stage is the “Discussion of Studies Conducted in the Established Domain of the Research Domain”, which evaluates the findings from the perspective of the existing body of knowledge. The flowchart closes with the “End” stage.

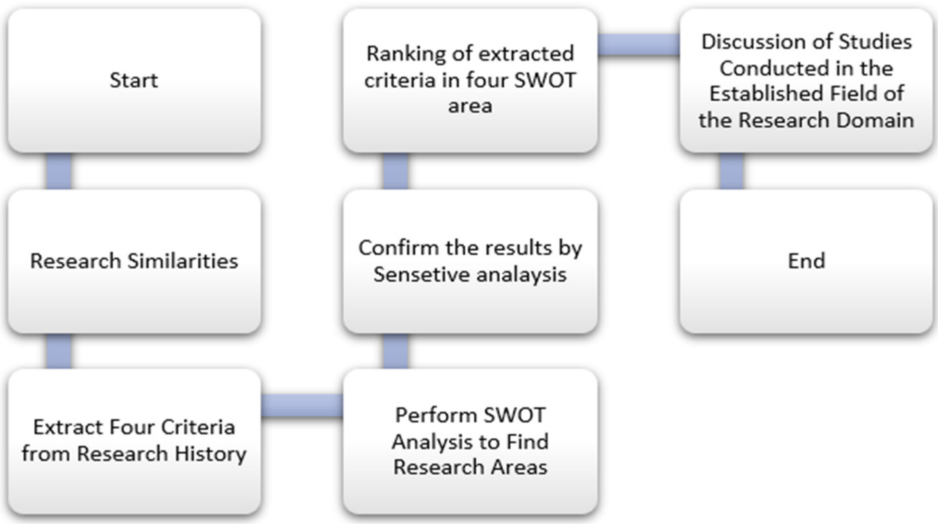

Figure 2. Flowchart of how to conduct research (Author).

3.1. Questionnaire Design and Details

The Analytic Hierarchy Process (AHP) method was used to design the questionnaire for this study, which was specifically designed to collect opinions on the integration of BIM and blockchain technologies for the construction of Mars. 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 the standard AHP numerical scale (from 1 to 9). This scale is designed in such a way that quantitative and qualitative comparisons can be converted into numbers. The data obtained from the questionnaire were analyzed to form pairwise comparison matrices and extract the relative weights of each of the criteria. The questionnaires were distributed electronically to ensure accessibility and confidentiality for the selected experts.

3.2. Experts' Choice

The selection of 10 experts for this study was based on the need for expert analysis. Given the research's specialized nature, ten experts' responses were sufficient to achieve the study objectives. The number of experts actively working on the topic and the difficulties in reaching them due to confidentiality restrictions led to the use of the opinions of 10 experts. These experts have worked extensively in the relevant field. Their ideas came from their professional backgrounds and involvement in Mars-related research, ensuring their contributions were legitimate and directly relevant to the study objectives. Their diversity of experience broadened the research findings and provided a comprehensive perspective. The expert opinions are based on the results of Mars exploration missions and research conducted by numerous rovers sent to the planet. These data-driven ideas are based on first-hand experience and analysis of findings from Mars-related studies. This strategy ensures that the research is based on solid information that improves the study's credibility and scientific rigor.

3.3. Integration of SWOT and AHP

The combination of SWOT and AHP approaches provides a comprehensive and quantitative approach to assessing the factors influencing the adoption of BIM and blockchain technologies in Martian buildings. SWOT analysis addresses internal (strengths and weaknesses) and external (opportunities and threats) variables and provides a structured framework for research analysis. SWOT does not have the advantage of prioritizing these criteria based on their relative importance. AHP adds a quantitative dimension by performing pairwise comparisons and assigning weighted rankings to each criterion. These weights indicate the relevance of each criterion in achieving strategic objectives, allowing for a more focused and actionable analysis. By combining these methodologies, this study provides a better understanding of the strategic state of BIM and blockchain technologies and identifies important areas that require immediate attention and additional research. This combined research ensures that decision-makers can focus on influential elements such as addressing infrastructure constraints and capitalizing on opportunities such as innovation in construction. Furthermore, this method's systematic and clear structure makes it particularly suitable for dealing with complex, multi-criteria judgments in the unique environment of extraterrestrial construction, providing a solid foundation for the development of Martian construction systems.

In the analysis based on the opinion of experts, it is better to use the snowball sampling method due to the difficulty of accessing experts. Therefore, by using this method, upon finding each expert and entering the research, he is asked to include people with similar conditions. This way, the sampling will be completed with a suitable convergence speed.

SWOT analysis (or SWOT matrix) is a strategic planning technique to help a person or organization identify strengths, weaknesses, opportunities, and threats related to business competition or project planning. SWOT assumes that strengths and weaknesses are often internal, while opportunities and threats are usually external. The name is an abbreviation of the four parameters examined by the technique:

- Strength (S): characteristics of the business or project that give it an advantage over others.
- Weaknesses (W): characteristics that put the business or project at a disadvantage compared to others.
- Opportunities (O) are elements in the environment that the business or project can take advantage of.

- Threats (T) are environmental elements that can cause problems for the business or project.

The concept of strategic fit expresses the degree of compatibility of the internal environment with the external environment (Table 2). Identifying SWOT is important because it allows people and organizations to plan the next steps to achieve the goal.

Table 2. Different areas of the SWOT method.

	Destructive	**The Builder**
Internal factors	W (weakness)	S (strengths)
External factors	T (threats)	O (opportunities)

In the following, the strategies that are the result of SWOT analysis are discussed:

- So, strategy (Maximax strategy): In fact, the purpose of this strategy (Strengths–Opportunities) is to maximize external opportunities by focusing on the identified strengths.
- WO, strategy (Minimax strategy): The Weaknesses–Opportunities strategy uses existing opportunities to reduce the effects of the organization's weaknesses.
- ST, strategy (Maximin strategy): In the Strengths–Threats strategy, the focus is 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 (Minimin strategy): The purpose of Weaknesses–Threats is to determine what decisions should be made to minimize the organization's weaknesses against the identified threats.

3.4. Calculation of the Matrix of External and Internal Factors

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 accurate as much as possible, and then they are separated into two categories: opportunities and threats.

Second step: Assign each factor a weighting coefficient between zero (unimportant) and one (very important). The sum of the assigned weight coefficients must be equal to one. The coefficients indicate the relative importance of the investigated 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), and (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.

Matrix of Internal Factors evaluation **(IFE)**: To calculate IFE matrix, all the steps taken for the matrix of external factors must be followed, this time for the opportunities and threats that have affected the organization.

3.5. AHP Method

For prioritization of the criteria, it is necessary to use suitable methods for multi-criteria decision-making [95]. In this research, according to the structure and relationship between the main criteria, the goal, and the sub-criteria, the AHP model, which is a subset of the analytic network process (ANP) method, was used [96,97].

First step: designing a paired questionnaire and completing it by experts.

Second step: is scoring the questionnaires based on the range of changes from 1 to 9, which are described in the following Table 3.

Table 3. 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	Option or index i is slightly more important than j.
3	Very preferred	Option or indicator i is more important than j.
4	Very much preferred	Option i is much more preferable than j.
5	Absolutely preferred	Option 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.

Third step: Using the matrix values of all the experts, these matrices are calculated as a geometric mean in each region and entered into the Expert Choice 11 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: Calculating the inconsistency rate, must be below 10%, and the following relationships are used to calculate this:

Calculation of the normalized values of the matrix of pairwise comparisons (A) using the arithmetic mean method (W) (Table 4):

$$\lambda = A.W$$

$$\lambda_{\max_i} = \frac{[A.W]_i}{W_i}$$

$$\lambda_{\max} = \frac{\lambda_{\max_1} + \lambda_{\max_2} + \ldots + \lambda_{\max_n}}{n}$$

$$I.I = \frac{\lambda_{\max} - n}{n - 1}$$

$$I.R = \frac{I.I}{I.I.R} < 0.1 \to Ok$$

Table 4. 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

Fifth step: If the inconsistency rate is correct, the output of the weights will be accepted through the software. The following extracted criteria are stated in different sections (Table 5).

Table 5. Extracted criteria (author).

Weakness	Strength
Complexity of technology Initial costs Resistance to change Limited infrastructure Legal problems Time-consuming implementation Sustainability of technology Problems of compatibility with Mars	Detailed modeling and construction instructions Management of resources and materials Cost calculation and budgeting Project management Improve quality and safety High precision Data management Collaboration between teams Continuous monitoring

Table 5. *Cont.*

Threat	Opportunity
Technical risks Defects in data security Difficult environmental conditions International competition Uncertainty about the future Need for training and skills	Innovation in construction Sustainable development Increase productivity Transparency in information Risk prediction and management Better project management Technological advances Improve coordination

4. Research Findings

In this part, descriptive statistics will be used to describe and analyze the data collected by the questionnaire from the sample of people. The integration of BIM and blockchain for the data management of Martian buildings has been evaluated using the SWOT method, and the results of this analysis are presented below.

In line with the analysis, the weights of each item presented to the experts should be calculated as strengths and weaknesses as well as opportunities and threats. For this purpose, these weights were calculated using the AHP method. First, by distributing a paired questionnaire among the experts included in the research, the weights of each item have been calculated, and these values can be seen in Table 6. First, a pair study was conducted for the strengths, and based on the studies based on the relationships presented in the previous section for the inconsistency rate, the inconsistency rate of this matrix was calculated to be around 3%, which is within the standard and permissible range.

Table 6. The weights of each of these items (Author).

	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	1	0.24	0.19	0.23	0.32	0.5	0.5	0.33	0.49
C2		1	0.79	2	2.52	3.97	4	1.94	2.96
C3			1	2	2.22	3.97	4	3	3.6
C4				1	1.89	3	3	1.87	2.31
C5					1	3	2.61	2	3
C6						1	2	2.19	1.76
C7							1	0.64	1.89
C8								1	2
C9									1

Pairwise comparison table of strengths: Table 6 illustrates the pairwise comparison of criteria based on their relative strengths. The weights assigned to each criterion reflect their importance, allowing for a comprehensive evaluation of the relationships between them.

Considering that the expert's decision matrix has a low inconsistency rate, it can be concluded that their opinions and judgments have acceptable coordination and coherence. This matter is of great importance because, in the AHP method, the inconsistency rate is one of the key criteria for evaluating the quality and accuracy of decisions. Therefore, it can be safely said that the weightings calculated from this matrix accurately and reliably reflect the priorities and relative importance of the options or criteria. This provides a reliable basis for final decisions and reduces the possibility of errors due to inconsistency in judgments.

From the presented Table 7, it can be concluded that "accurate modeling" and "manufacturing instructions", as key factors, have more weight than other items and, therefore, have higher importance. This shows that from the point of view of experts, paying attention to these two factors plays an essential role in achieving project goals or improving processes. The high importance of these factors can be due to their direct impact on quality, efficiency, and reducing errors in executive processes. Therefore, focusing on improving modeling and developing detailed guidelines can guarantee greater success compared to other subjects.

Table 7. Weighting provided by the AHP method (author).

Rank	Object	Weight
1	Detailed modeling and construction instructions	0.07
2	High precision	0.06
3	Data management	0.06
4	Continuous monitoring	0.06
5	Collaboration between teams	0.05
6	Project management	0.04
7	Management of resources and materials	0.03
8	Improve quality and safety	0.03
9	Cost calculation and budgeting	0.01

Strength sensitivity analysis table and chart: Sensitivity analysis of strengths (Table 8, Figure 3) shows how differences in criteria weights affect their relative importance. To ensure robustness of the analysis, the weight of each criterion was varied by ±10%. Criteria such as "accurate modeling and manufacturing instructions" (0.07), "high accuracy" (0.06) and "data management" (0.06) have moderate sensitivity, with adjusted weights ranging from 0.063 to 0.077 and 0.054–0.066, respectively. Lower weight criteria, such as "cost calculation and budgeting" (0.01), had minor fluctuations, with adjusted weights ranging from 0.009 to 0.011. The research shows that the ranking of higher weight criteria remains relatively stable, highlighting their importance in the overall assessment. However, minor changes in lower weight criteria have little impact on the results of the analysis, proving the reliability of the prioritization approach.

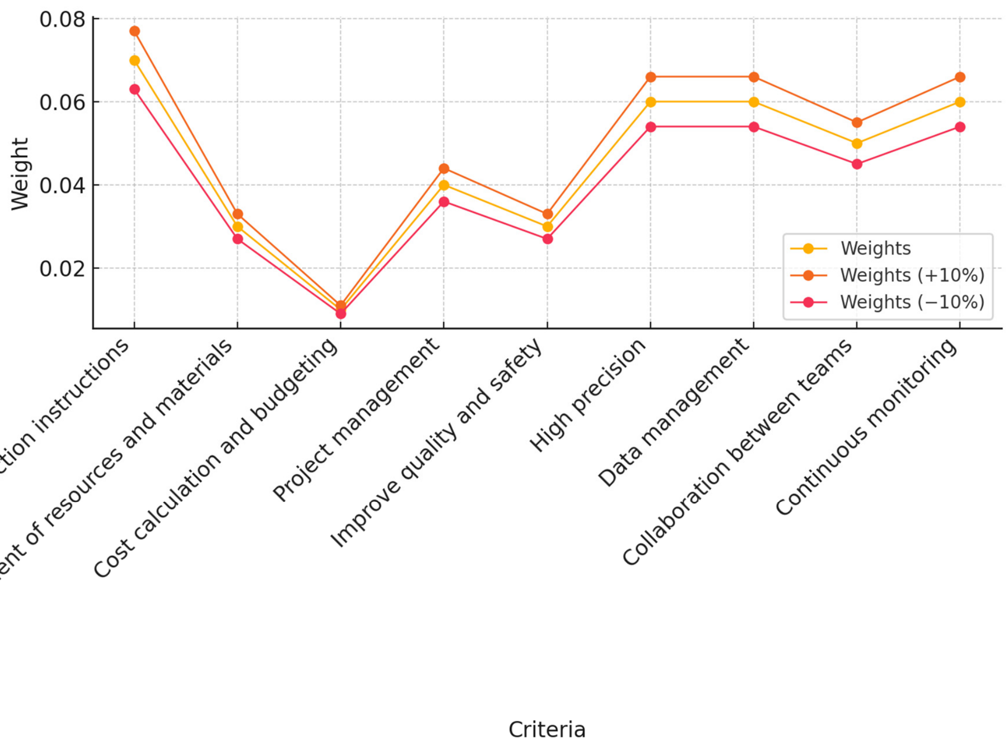

Figure 3. Strengths sensitivity analysis.

Table 8. Strength sensitivity analysis.

No	Criteria	Weights	Weights (+10%)	Weights (−10%)
1	Detailed modeling and construction instructions	0.07	0.077	0.063
2	Management of resources and materials	0.03	0.033	0.027
3	Cost calculation and budgeting	0.01	0.011	0.009
4	Project management	0.04	0.044	0.036
5	Improve quality and safety	0.03	0.033	0.027
6	High precision	0.06	0.066	0.054
7	Data management	0.06	0.066	0.054
8	Collaboration between teams	0.05	0.055	0.045
9	Continuous monitoring	0.06	0.066	0.054

The investigations carried out on the geometric result of the experts' answers calculated the inconsistency rate in this matrix as 5.26%, which shows that the consistency of the answers has been confirmed. The results of experts weighing the weak points are also presented below Table 9.

Table 9. The results of weighting of weaknesses by experts (Author).

	C1	C2	C3	C4	C5	C6	C7	C8
C1	1	5.01	2.96	0.49	6.02	4.03	3.14	2.81
C2		1	0.64	0.15	2	0.84	0.48	0.48
C3			1	0.24	2.47	1.9	0.76	0.75
C4				1	0.14	0.20	0.32	0.30
C5					1	1.85	2.79	2.22
C6						1	2.38	2.47
C7							1	2
C8								1

When examining the matrix of pairwise comparisons of the results provided by the experts, it should be stated that the inconsistency rate is lower than the 10% allowed standard, so the final weighting can be presented with high confidence.

Table 10 presents the weights assigned to various factors based on their relative importance. These weights highlight the significance of each factor in evaluating the strengths and challenges.

Table 10. The inconsistency rate is lower than the 10% allowed standard.

Rank	Object	Weight
1	Limited infrastructure	0.27
2	Complexity of technology	0.25
3	Problems of adapting to the conditions of Mars	0.19
4	Legal problems	0.15
5	Time consuming implementation	0.13
6	Sustainability of technology	0.10
7	Resistance to change	0.09
8	Initial costs	0.06

Weakness sensitivity analysis table and chart: The sensitivity analysis of the weaknesses in (Table 11, Figure 4) shows the effect of ±10% weight changes on the importance of each criterion. High-weight factors, such as "limited infrastructure" (0.27) and "technology complexity" (0.25), show high sensitivity, with adjusted weights ranging from 0.243 to 0.297 and 0.225–0.275, respectively, indicating substantial importance. Significantly weighted criteria, such as "Mars compatibility issues" (0.19) and "legal issues" (0.15), show significant sensitivity. In contrast, low-weight factors, such as "initial costs" (0.06) and "technology sustainability" (0.10), have little impact, indicating stability in the analysis. The figure illustrates these differences, with steeper slopes for high-weighted criteria and flatter curves for low-weighted criteria, supporting the prioritization of significant deficiencies and guiding strategic focus.

Table 11. Weakness sensitivity analysis.

No	Criteria	Weights	Weights (+10%)	Weights (−10%)
1	Complexity of technology	0.25	0.275	0.225
2	Initial costs	0.06	0.066	0.054
3	Resistance to change	0.09	0.099	0.081
4	Limited infrastructure	0.27	0.297	0.243
5	Legal problems	0.15	0.165	0.135
6	Time-consuming implementation	0.13	0.143	0.117
7	Sustainability of technology	0.10	0.110	0.090
8	Problems of adapting to Mars	0.19	0.209	0.171

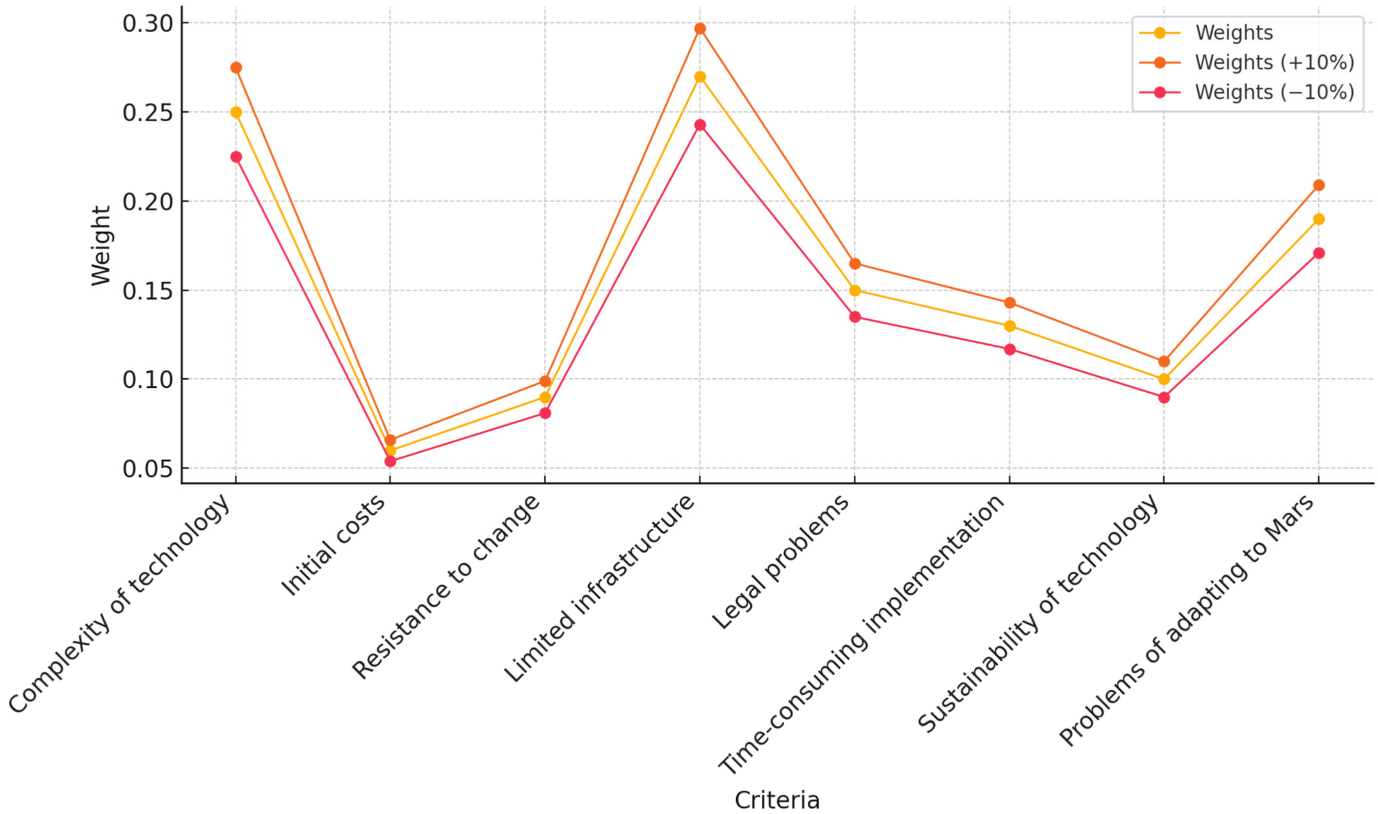

Figure 4. Weakness sensitivity analysis.

Table 12 examines opportunities using pairwise comparisons of various criteria. The weights assigned to each criterion indicate their relative importance in identifying and exploiting potential opportunities.

The results of the inconsistency rate analysis showed that the rate for the matrix of pairwise comparisons of the presented result is equal to 3.24%, so that the final weighting can be presented with high confidence in the accuracy of the data.

Innovation in construction was of higher importance among the mentioned opportunities Table 13. The investigation on the weighting of the threats continued using the AHP method, and the inconsistency rate for the threats was calculated as 2.15, which showed the experts' high accuracy in answering.

Table 12. Examining opportunities.

	C1	C2	C3	C4	C5	C6	C7	C8
C1	1	0.23	0.49	0.32	0.33	0.2	0.15	0.25
C2		1	2.61	2	1.83	0.24	0.64	2
C3			1	1.83	1.89	4.06	4.96	3
C4				1	1.97	2.88	3.97	2
C5					1	2.91	3.64	2
C6						1	1.78	0.2
C7							1	0.62
C8								1

Table 13. Opportunities (author).

Rank	Object	Weight
1	Innovation in construction	0.23
2	Increase productivity	0.18
3	Transparency in information	0.15
4	Sustainable development	0.14
5	Risk prediction and management	0.14
6	Better project management	0.13
7	Improve coordination	0.13
8	Technological advances	0.11

Opportunity point sensitivity analysis table: The sensitivity analysis of the opportunities (Table 14, Figure 5) shows how ±10% changes in the weights affect the importance of each criterion. High-weight factors such as "Innovation in Construction" (0.23) and "Increased Productivity" (0.18) show significant sensitivity, with adjusted weights ranging from 0.207 to 0.253 and 0.162–0.198, respectively, which emphasizes their critical role in exploiting the opportunities. Medium-weight criteria such as "Transparency in Information" (0.15) and "Anticipation and Risk Management" (0.14) show moderate sensitivity, while low-weight factors such as "Technological Advances" (0.11) show minimal impact with adjusted weights ranging from 0.099 to 0.121. This analysis confirms that the opportunities with higher weights are still the most influential.

Table 15 analyzes threats by providing a pairwise comparison of various criteria based on their relative impact. The weights indicate the significance of each threat, with higher values reflecting greater risks.

Since the presented pairwise comparison matrix had a small inconsistency rate, the final weighting of the criteria can be presented based on this matrix, which can be seen below. Table 16 shows that data security defects are the most important threat.

Table 14. Opportunity Point Sensitivity Analysis.

No	Criteria	Weights	Weights (+10%)	Weights (−10%)
1	Innovation in construction	0.23	0.253	0.207
2	Sustainable development	0.14	0.154	0.126
3	Increase productivity	0.18	0.198	0.162
4	Transparency in information	0.15	0.165	0.135
5	Risk prediction and management	0.14	0.154	0.126
6	Better project management	0.13	0.143	0.117
7	Technological advances	0.11	0.121	0.099
8	Improve coordination	0.13	0.143	0.117

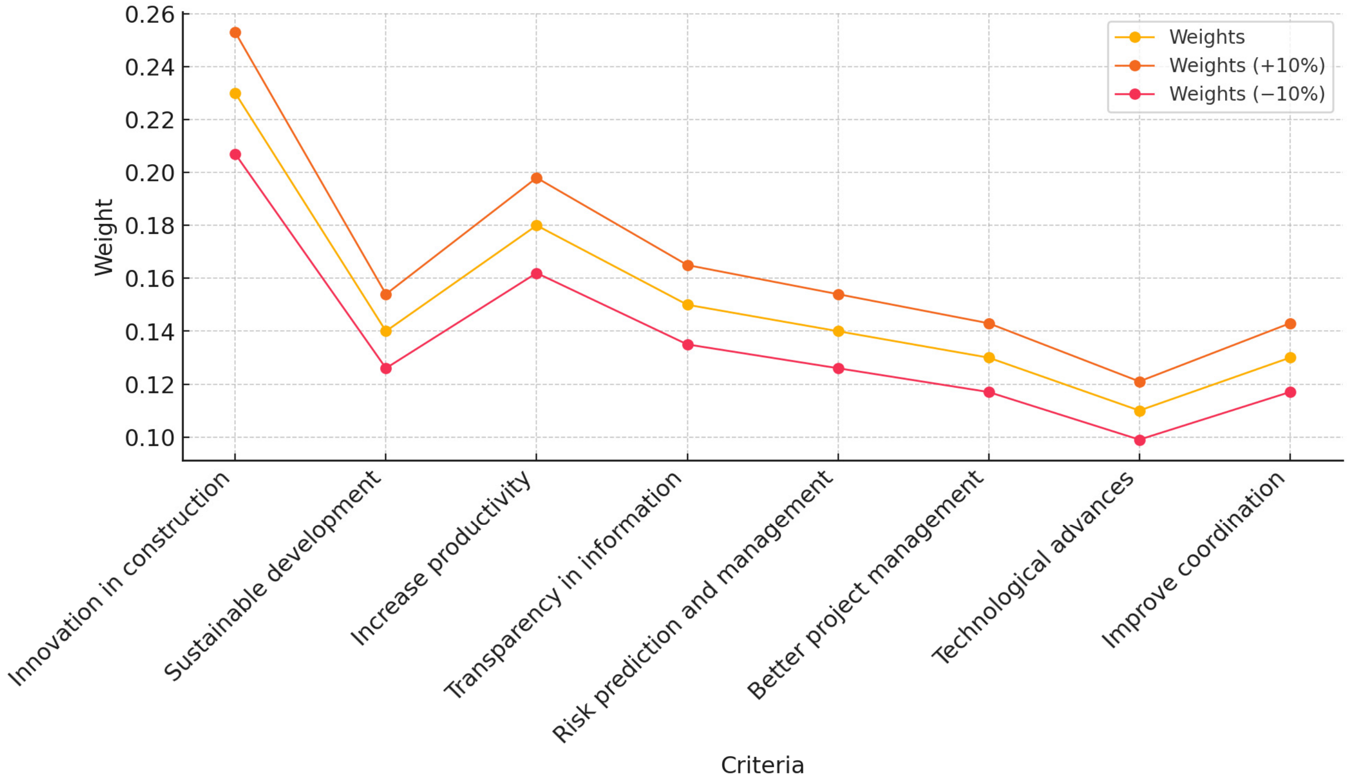

Figure 5. Opportunity point sensitivity analysis.

Table 15. Threats (Author).

	C1	C2	C3	C4	C5	C6
C1	1	0.3	0.49	3.84	3.38	1.69
C2		1	1.69	6.12	4.66	3.88
C3			1	4.96	4.19	2.76
C4				1	0.5	0.3
C5					1	0.5
C6						1

Table 16. The most important threat among subjects.

Rank	Object	Weight
1	Defects in data security	0.34
2	Difficult environmental conditions	0.25
3	Technical risks	0.17
4	Need for training and skills	0.12
5	Uncertainty about the future	0.07
6	International competition	0.04

Threats point sensitivity analysis table and chart: The sensitivity analysis of threats (Table 17, Figure 6) assesses how ±10% weight variations impact each criterion's relevance. High-weighted factors such as "Defects in data security" (0.34) and "Difficult environmental conditions" (0.25) have significant sensitivity, with adjusted weights ranging from 0.306 to 0.374 and 0.225–0.275, respectively, emphasizing their vital importance. Moderate-weighted factors such as "Technical risks" (0.17) and "Need for training and skills" (0.12) have moderate sensitivity, whilst lower-weighted threats such as "International competition" (0.04) show negligible changes, with weights ranging from 0.036 to 0.044. The figure illustrates these differences, with steeper slopes for higher-weighted threats and flatter curves for lower-weighted threats, emphasizing the importance of prioritizing high-impact threats while ensuring general robustness in the study.

Table 17. Threats point sensitivity analysis.

No	Criteria	Weights	Weights (+10%)	Weights (−10%)
1	Technical risks	0.17	0.187	0.153
2	Defects in data security	0.34	0.374	0.306
3	Difficult environmental conditions	0.25	0.275	0.225
4	International competition	0.04	0.044	0.036
5	Uncertainty about the future	0.07	0.077	0.063
6	Need for training and skills	0.12	0.132	0.108

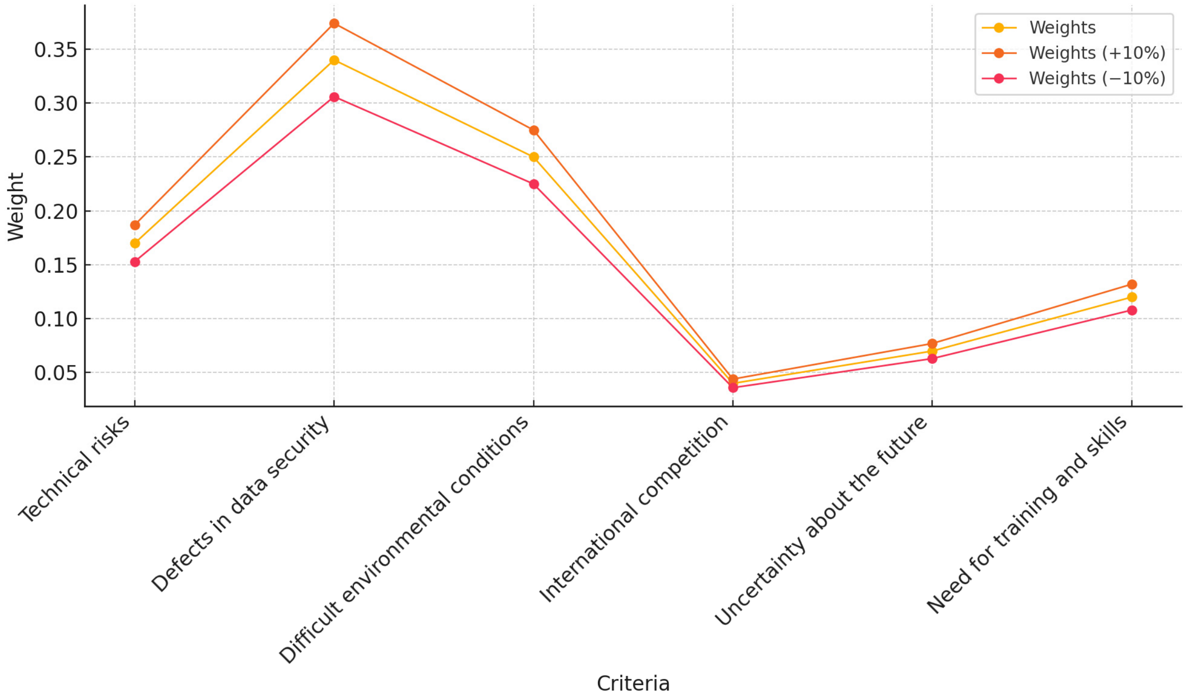

Figure 6. Threats point sensitivity analysis.

In the next step, the experts were asked to score the items of opportunity, threat, strength, and weakness. By multiplying this score by the weight of each item, which was calculated using the AHP method, the weighted score was calculated for each item and continued. A SWOT analysis will be presented in Table 18.

As it is clear from the above Figure 7, detailed modeling of manufacturing instructions, high accuracy, data management, and continuous monitoring have the highest priority in strengths and limited infrastructure, technology complexity, technology stability, and problems of adapting to the conditions of Mars have the highest score in the items of weaknesses for the use and integration of BIM and Blockchain in Martian buildings is for information management. It can be seen that the presented ranking is similar to the AHP weighting method, which is natural, and these two coefficients normalize to each other. The following provides the analysis of opportunities and threats and the calculation of their weighted coefficients.

Figure 8 presents a sensitivity analysis of internal factors (strengths and weaknesses) in the IFE matrix. The blue, green, and red lines represent the weights of strengths and their 10% changes, while the orange, green, and red lines represent the weights of weaknesses and their corresponding changes.

Table 19 shows the weighted scores of external factors as part of the EFE (External Factor Evaluation) matrix in Opportunities and Threats.

Table 18. Weighted score for each of the items.

IFE Matrix				
	Strengths points			
Code	Agent	Score	weight	Weighted score
S1	Detailed modeling and construction instructions	3.81	0.07	0.00050
S2	Management of resources and materials	23.31	0.03	0.00260
S3	Cost calculation and budgeting	26.21	0.01	0.00373
S4	Project management	18.32	0.04	0.00221
S5	Improve quality and safety	16.12	0.03	0.00190
S6	High precision	10.14	0.06	0.00107
S7	Data management	7.26	0.06	0.00097
S8	Collaboration between teams	9.92	0.05	0.00126
S9	Continuous monitoring	6.01	0.06	0.00084
	plural			0.015
	Weak points			
Code	Agent	Score	weight	Weighted score
W1	Complexity of technology	25.488	0.25	0.011
W2	Initial costs	5.811	0.06	0.004
W3	Resistance to change	9.045	0.09	0.004
W4	Limited infrastructure	14.421	0.27	0.008
W5	Legal problems	15.697	0.15	0.010
W6	Time consuming implementation	13.209	0.13	0.006
W7	Sustainability of technology	10.592	0.10	0.005
W8	Problems of adapting to the conditions of Mars	9.367	0.19	0.005
	Total sum			0.053
	The result of subtracting the number of strengths from weaknesses			−0.038

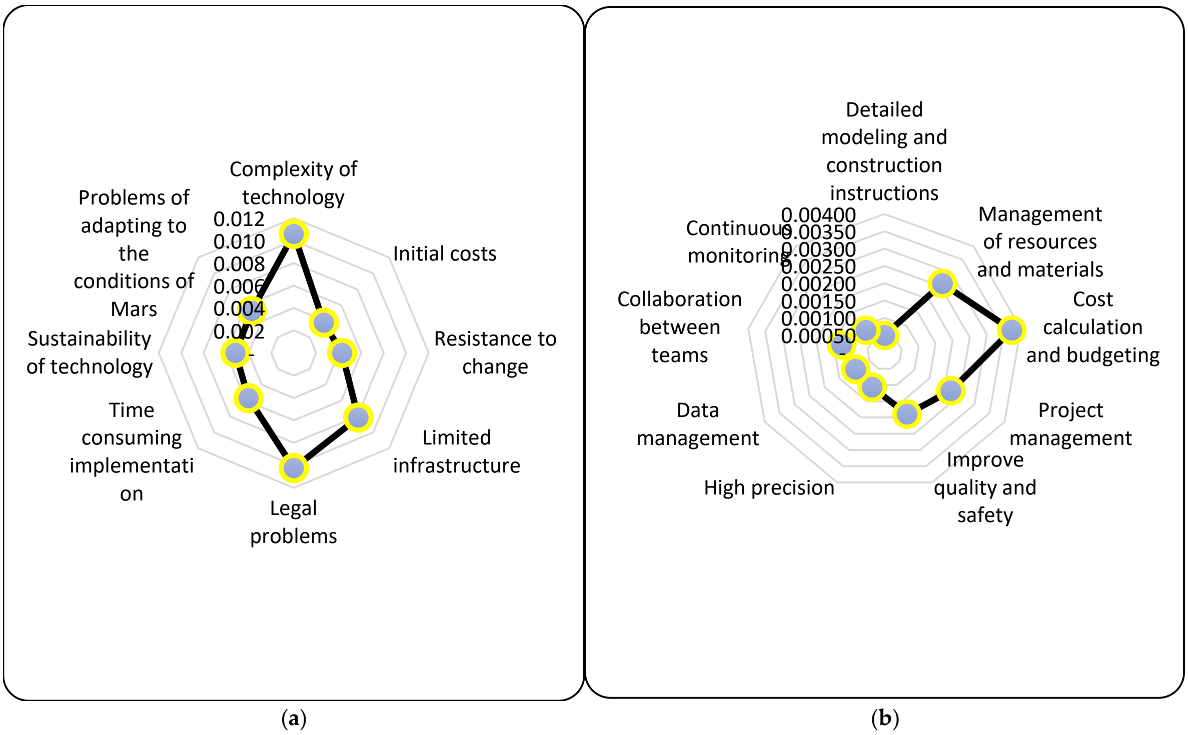

Figure 7. (**a**) Weak points and (**b**) strength modeling internal factors (author).

As it is clear from the above diagram (Figure 9), innovation in construction, increasing productivity, transparency in information and forecasting, and risk management are among the items with the highest score in opportunities, and defects in data security, difficult environmental conditions, and technical risks are also among the items with the highest ranking in threats in SWOT analysis is for the use and integration of BIM and blockchain in Martian buildings for information management. Considering the difference in the total weights of opportunity and threat as well as strength and weakness, it can be decided whether BIM and blockchain can be used to manage the information of Martian buildings or not, which has been carried out in the continuation of this work.

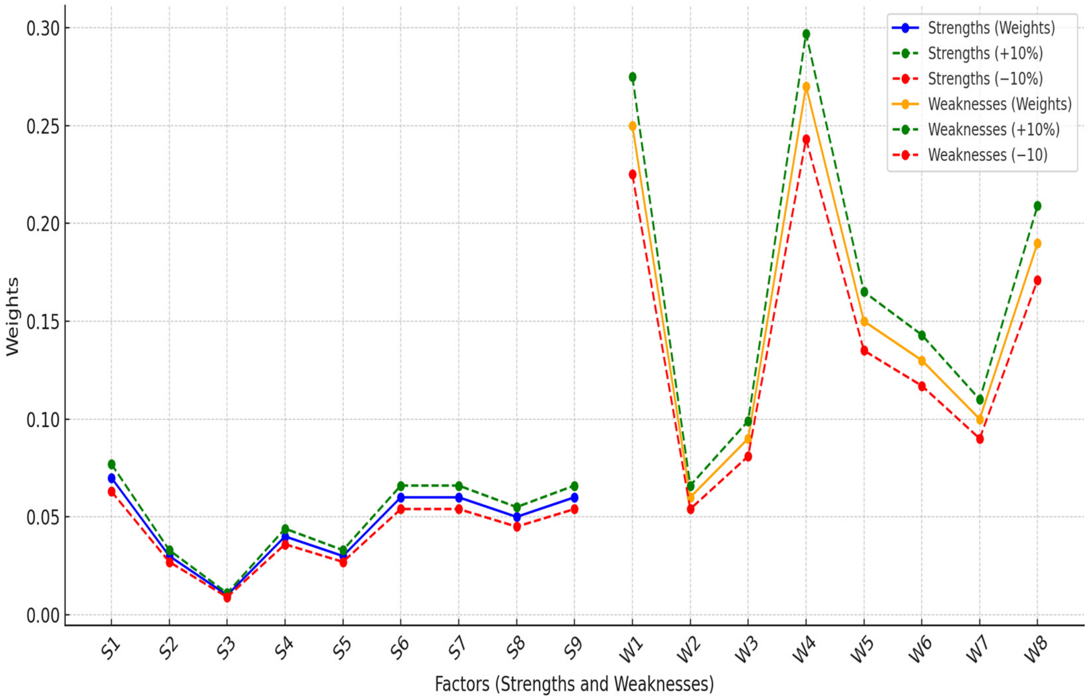

Figure 8. Sensitivity analysis of internal factors.

Table 19. Weighted score for each of the items (Author).

IFE Matrix				
	Opportunities points			
Code	Operator	Score	weight	Weighted score
O1	Innovation in construction	2.97	0.23	0.002
O2	Sustainable development	14.67	0.14	0.008
O3	Increase productivity	19.16	0.18	0.010
O4	Transparency in information	15.99	0.15	0.010
O5	Risk prediction and management	14.16	0.14	0.011
O6	Better project management	13.08	0.13	0.009
O7	Technological advances	11.14	0.11	0.008
O8	Improve coordination	13.45	0.13	0.009
	Total sum			0.068
	Weak points			
Code	Operator	Score	weight	Weighted score
T1	Technical risks	10.70	0.17	0.014
T2	Defects in data security	20.68	0.34	0.016
T3	Difficult environmental conditions	15.54	0.25	0.010
T4	International competition	2.43	0.04	0.003
T5	Uncertainty about the future	4.25	0.07	0.006
T6	Need for training and skills	7.55	0.12	0.009
	Total sum			0.059
	The result of subtracting the number of strengths from weaknesses			0.009

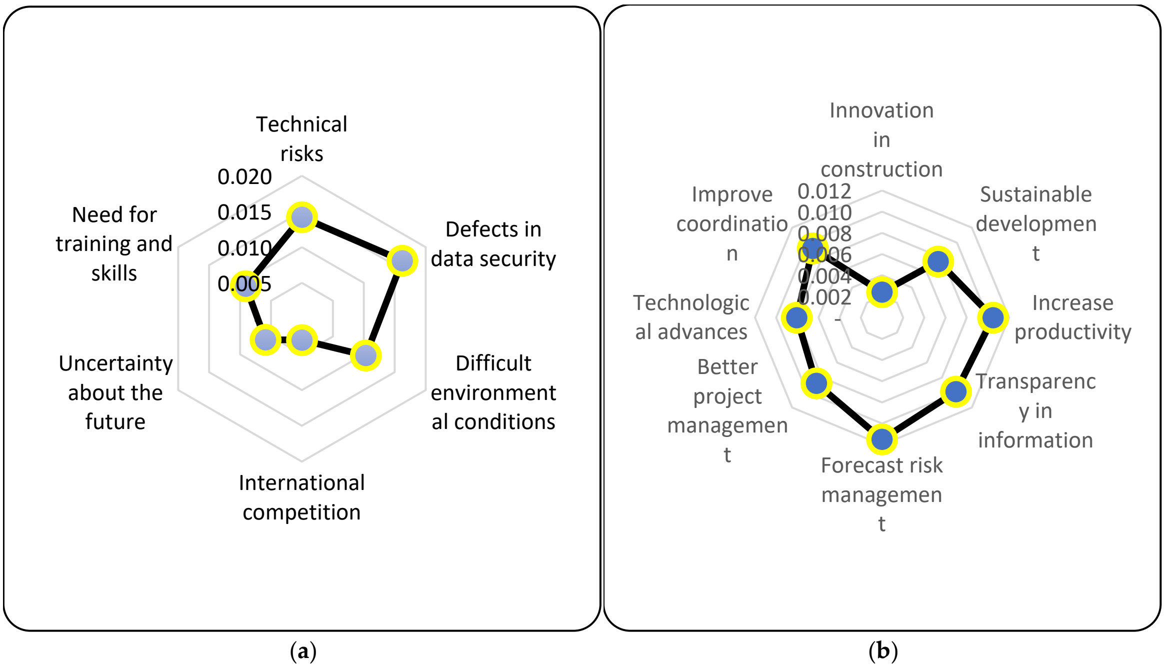

Figure 9. (**a**) Threats and (**b**) opportunities modeling external factors (Author).

Figure 10 depicts the sensitivity analysis of external factors (opportunities and threats) in the EFE matrix. The graph shows how weight differences of ±10% affect factor priority.

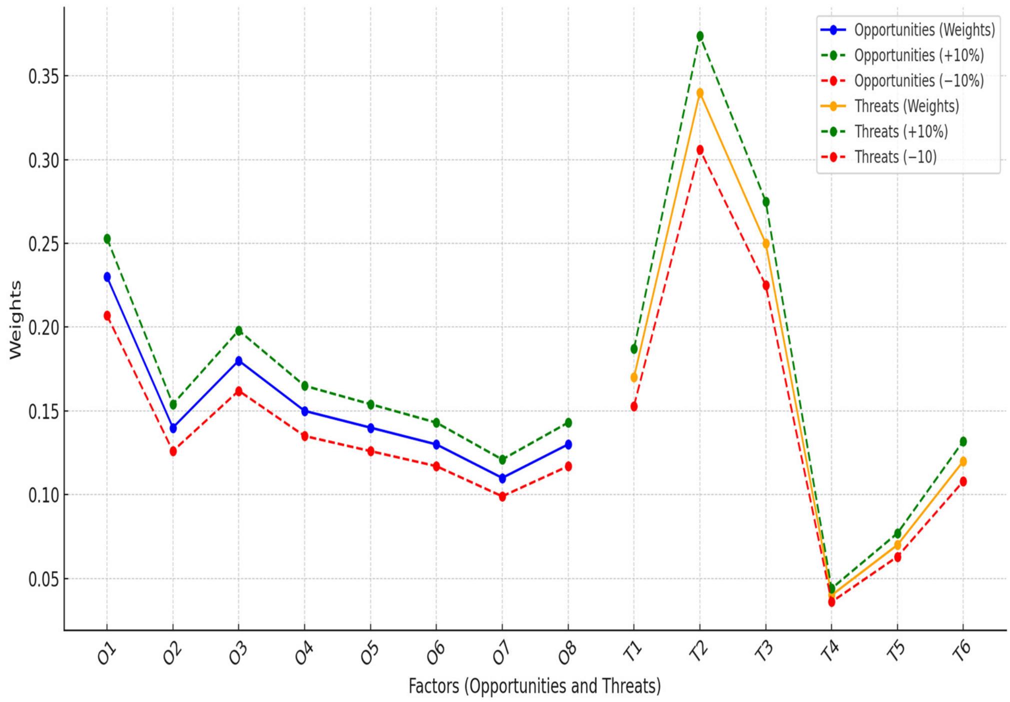

Figure 10. Sensitivity analysis of external factors.

Opportunities (blue, green, and red lines) show significant sensitivity with clear fluctuations in the range of ±10%.

For threats (orange, green, and red lines), they show minimal fluctuations, indicating their limited influence.

As seen from Figure 11, the strategy of integrating BIM with blockchain is in the conservative strategy area. Therefore, to use this technology in the information management of Martian buildings, more extensive research should be carried out, and all its dimensions should be evaluated before it can be implemented. Considering the area of the research area, according to the AHP and SWOT analysis, the limited infrastructure criterion is an obstacle that the activists in this field must find. Also, innovation in construction should be carried out on Mars so that this technology can be considered in the construction of Martian buildings. This project can be implemented and finalized.

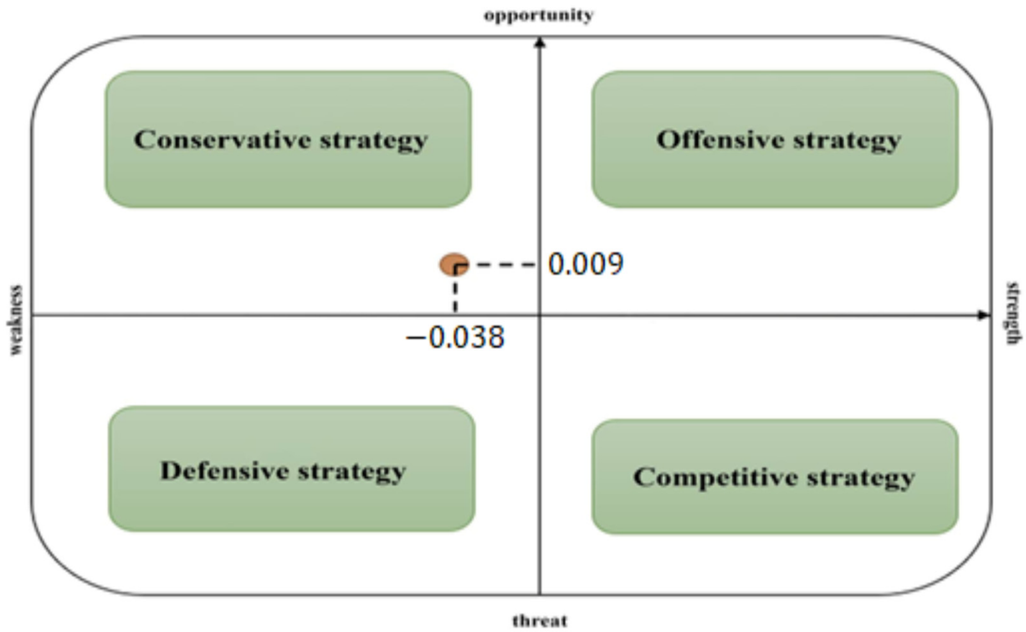

Figure 11. Integrating BIM with blockchain is a conservative strategy (author).

5. Conclusions

This research investigated the feasibility and dependability of combining Building Information Modeling (BIM) and blockchain technology to manage information in Martian structures during extraterrestrial construction. The study's objectives were met by identifying key strengths, weaknesses, opportunities, and threats (SWOT) and analyzing their strategic implications utilizing the Analytical Hierarchy Process. The findings demonstrate both the potential and limitations of this integration, paving the way for future research and development. The findings reveal that BIM and blockchain integration have numerous benefits, including detailed modeling and construction instructions, high data accuracy, effective data administration, and continuous monitoring. These attributes are crucial for addressing the unique challenges of Martian buildings, which need precision and dependability. The ability to manage resources and monitor building performance in real-time ensures that Martian buildings operate efficiently and safely. The research identified significant difficulties that must be addressed before the deployment can be done effectively. Significant problems include Mars' limited infrastructure, technological complexity, high starting expenditures, and difficulty adapting technology to Martian circumstances. These constraints highlight the critical need for significant infrastructural investment and technical innovation to overcome these concerns. The study presents chances to demonstrate BIM's revolutionary potential and blockchain integration. Innovation in construction processes, increased efficiency, and improved risk management are all key benefits that can transform Martian building standards. Furthermore, the transparency and scalability of these technologies open up new avenues for long-term sustainable development in alien ecosystems.

Despite these opportunities, dangers, including data security flaws, technical issues, and severe Martian environmental conditions, jeopardize the system's dependability and sustainability. The research underlines the significance of implementing robust security policies and fail-safe solutions to tackle these dangers and safeguard the information management process. The results of the SWOT and AHP analyses position this integration in the conservative strategy quadrant, implying that, while the concept is interesting, further research and development are needed before implementation. The study emphasizes inadequate infrastructure as the most critical obstacle, emphasizing the need for new construction techniques and technologies to adapt to Mars' unique climate. Overcoming these challenges is critical for realizing the full potential of BIM and blockchain integration. This study assesses the advantages, limitations, opportunities, and hazards of combining BIM and blockchain in Martian buildings. It emphasizes the need for thorough research in minimizing vulnerabilities and risks while capitalizing on new opportunities. Future research should focus on constructing frameworks for dealing with Martian construction information, comparing them to previous studies, and exploring novel approaches to improve the reliability and feasibility of this integration. By advancing these efforts, researchers can pave the path for successful extraterrestrial construction, achieving the study's goals while also adding to the larger area of space exploration technology.

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Informed Consent Statement: Ethical review and approval were not required or waived for this study due to the study involving anonymous data collection and no personal information was gathered. More so, the study respondents participated voluntarily and were informed of the anonymity and confidentiality of the Delphi survey, hence no personal information is evident in the submitted manuscript.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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