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Critical Success Factors for Building Information Modeling Implementation as a Sustainable Construction Practice in the UAE

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Abstract: The building sector is widely acknowledged as a driving force behind national prosperity. However, there are considerable challenges to the construction industry's transition to sustainable practices, including regarding building information modelling (BIM) technologies. The United Arab Emirates has made significant progress in the Middle East in adopting BIM technologies. Green building approaches have been advanced through their incorporation into environmentally conscious building practices, with a large body of literature responding to this issue. Several projects in the United Arab Emirates have, however, made use of the complementary nature of BIM and UAE sustainable policies. However, not everybody has employed the full potential of BIM implementation in sustainable construction. This paper aims to identify and prioritize the critical success factors (CSFs) for effective BIM implementation as a sustainable construction practice in the UAE and examine their ranking and relationships. A list of critical success factors was gathered from a review of previous literature to identify the essential factors for successful implementation. A standardized questionnaire was distributed to consulting organizations and engineering enterprises to verify the existence of these CSFs and measure their importance in the context of the UAE's construction industry. The survey data was analyzed using the analytic hierarchy process (AHP) technique to elaborate and validate the results, which was specifically applicable to the needs of this study. The results from the AHP analysis show that the social aspects were ranked as the highest critical success factor compared to the other criteria, namely economic, environmental, and information technology. Within this criterion, it was found that effective communication among stakeholders is the most important element, as subject matter experts feel that it is imperative to have buy-in from all or most of the construction project stakeholders to achieve the strategic goal of implementing BIM. Equally anticipated are both an effective corporate framework to back up the BIM system and government funding to build the BIM system.

Keywords: BIM; sustainable construction; critical success factors; AHP; sustainability; UAE; expert opinion survey

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1. Introduction

The National Institute of Standards and Technology (NIST) in the United States (U.S.) estimates that the construction sector loses around USD 15.6 billion annually, or about 4% of its annual income, due to inefficient connectivity and project data management challenges. As a result, the construction sector has shifted to building information modeling (BIM) to mitigate the impact of the data interoperability challenges in the construction industry [1]. BIM is an innovative approach that enables the sharing and interoperability of data among stakeholders specific to construction projects. It has helped complete projects on time and within budget, while boosting productivity and efficacy [2,3]. Many construction stakeholders have, therefore, adopted BIM and implemented it in different domains [2,4]. Yet, despite all the government initiatives and attempts to support BIM implementation, there is still a lack of understanding of the overall BIM application, which includes sustainability (TBL) success factors. Some factors that support the successful implementation of BIM are called critical success factors (CSFs).

CSFs have been defined and described by several authors [5–8]. Sanvido et al. [9] described CSFs as "elements that foresee achievement instead of simply the unadulterated survival of a construction project". Toor and Ogunlana [10] stated that a CSF "denotes a certain element which significantly contributes to and is remarkably vital for the achievement of a project". Moreover, Babu and Sudhakar [11] considered CSFs to be factors with the most significance in preventing project suspensions and guaranteeing the success of construction projects. Besides, BIM is linked to clean construction, green principles, and integrated project delivery, which reflect its goal of creating value and improving collaboration along the supply chain, according to Ozorhon and Karahan [12], and therefore, supporting sustainability in the construction industry.

Many CSFs have been identified in the literature for the effective implementation of BIM [5,6,13–15]. Yet, there are no studies that have grouped and prioritized CSFs in the context of the UAE's construction sector. Moreover, no studies have been conducted to identify the CSFs for effective BIM implementation as a sustainable construction practice. Accordingly, this research aims to identify and prioritize the CSFs for BIM implementation as a sustainable construction practice in the UAE, using the analytical hierarchy process (AHP) and subject matter expert interviews. The next section reviews the interconnection between BIM implementation and sustainable construction CSFs, before the research methodology, analysis, and results are discussed.

1.1. BIM in the Sustainable Construction Context

The construction industry is considered one of the key pillars for the economic growth of any nation. It accounts for USD 1.7 trillion worldwide and, in most countries, it impacts 5–7% of the total gross domestic product (GDP), meaning it contributes significantly to the national GDP, in effect, making it essential to socio-economic and economic growth, and the development of countries [16,17]. All construction activities in terms of operation, maintenance, renovation, and demolition are considered to be a significant cause of air pollution, and water depletion, responsible for 36% of the world's energy consumption, 35–40% of global CO_2 emissions, and 30% of global greenhouse gas emissions [17,18].

Sustainable construction processes prioritize environmental conservation, human rights, and social and economic equity [19]. Hence, sustainable building is a process that balances ecological, financial, and social considerations throughout the structure's life cycle [20]. Moreover, there are many innovative technologies for achieving the aim of sustainable construction. One such innovative approach is BIM. The United States National Building Information Model Standard Project Committee defines BIM as "A digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decision during its life cycle; defined as existing from earliest conception to demolition" [21]. BIM is a database of data collected at various stages of a building's life cycle (from planning to deconstruction) that may be used to make informed decisions. Sustainable building practices can be implemented at every stage of the building life cycle (from design to construction to maintenance and decommissioning) with the help of BIM [22,23]. Specifically, green design, which involves creating and maintaining a safe and environmentally friendly structure, is at the heart of sustainable BIM implementation [24,25]. Regarding environmental sustainability, BIM allows for more eco-friendly choices to be made across the construction's entire lifespan, cutting down on adverse environmental impacts in areas like resource depletion, waste disposal, and carbon emissions. In addition to supporting the economy long-term, economic sustainability also facilitates the early diagnosis of possible conflicts and the making of more informed engineering decisions. In contrast, BIM promotes social sustainability by making towns more habitable by enhancing wastewater treatment and air quality in buildings, noise pollution, construction site health and security, and requiring fewer disruptions to public infrastructure [23]. Therefore, this demonstrates that BIM has the potential to be used as an instrument for green building, linking the people, planet, and profit tenets of sustainability.

1.2. The Importance of the Effective Implementation of Building Information Modelling

According to Evans and Farrell [26], the implementation of BIM in the construction industry is driven by the need to overcome substantial challenges in the sector. For example, to facilitate the use of alternative energy by analyzing the efficiency and endurance of solar panels. A previous study by Wong and Fan [27] found that the proper implementation of BIM can provide vital information for improving the design, design optimization, integrated project delivery, and building performance, contributing to improving the performance of a construction project's life cycle. Another study by Ahmad and Thaheem [28] perceived BIM as a tool for creating a sustainable built environment through practical building projects and a contributor to holistic designs and modeling approaches essential for achieving economic competitiveness, such as generative design approaches using BIM tools.

However, the limited evidence on the contribution of BIM to the sustainability and economic competitiveness of buildings poses a challenge to establishing its actual contribution to a country's economic development [28]. Regardless, Olawumi et al. [29] argue that the economic significance of BIM is founded on its contribution to better design and multi-design alternatives, increasing a building's usefulness. Similarly, other researchers [13,30–32] have shown that using BIM in the building business helps with model-based cost planning, which reduces hazards and expenses. The National BIM Council of Ireland found that using BIM for building projects can reduce construction expenditures by no less than 20%, which would have a beneficial financial effect. Moreover, Amuda-Yusuf [6] affirms that using BIM successfully enhances the reliability of a construction project, allowing for adequate cost-saving planning.

Conspicuously, D. W. Chan et al. [2] highlight that the social benefits of BIM use in building projects can be evaluated. To this end, well-implemented BIM will increase a construction project's quality by facilitating enhanced interaction and cooperation between the various parties involved in the building process. Additionally, Fei et al. [33] mentioned that BIM causes building projects to yield economically quantifiable improvements in quality. As a result, businesses and economies benefit from a resolution to a long-standing problem. BIM supports economic development throughout all echelons of society by representing buildings at a micro level, considering the economic demands and desires of a given location [34]. In contrast, Khahro et al. [35], critics of BIM, have said that it is difficult to determine how much it contributes to GDP development because it requires factoring in things like a building's carbon footprint and operating expenses.

1.3. Benefits and Challenges of BIM

Implementing BIM has numerous positive effects, including its contribution to sustainability. Secondly, sustainable building materials have been chosen using building information modeling and have boosted the sustainability metrics related to buildings, such as reducing carbon emissions, increasing clean energy, and creating more environmentally friendly communities. Further, BIM has the potential to enhance sustainable procedures for building initiatives, such as the administration and assessment of energy consumption in buildings, according to various publications [36]. Another method through which BIM aids in sustainable development is by creating a program to evaluate the deconstructability of a project's layout, to reduce waste and maximize material efficiency [37]. Sustainable development and the creation of green buildings, made possible in part by the use of BIM in building projects, will enhance individual wellness, owner work efficiency, organizational brand recognition, and eco-friendly communities by minimizing the adverse effects of properly constructed structures on the social and environmental realms. Despite the usefulness of BIM software for simulating sustainability characteristics, most programs limit themselves to environmental considerations. Only a small percentage of people have considered BIM's advantages in light of the three tenets of sustainability [36].

Despite the benefits of BIM in sustainable construction, its implementation in this context presents challenges. A significant barrier, particularly relevant in developing nations, is the addition of costs to a construction project due to the need for a greater understanding of the advantages of sustainability [20]. Another obstacle is the fear of higher investment costs for sustainable buildings versus conventional buildings. Unanticipated costs are frequently cited as challenging for sustainable buildings [25]. The proper strategic direction to promote the application of BIM in sustainable development is a further difficulty identified by Manzoor et al. [20]. To meet such cost challenges the potential profit needs to outweigh the implementation costs [23]. As seen in the literature, the major challenge for BIM implementation in sustainable construction is cost.

1.4. CSFs for Effective Building Information Modeling Implementation

Critical success factors in BIM are considered to be of emerging importance in the construction industry, due to their effect on harnessing automation in the industry while reducing errors and mistakes [38]. Low efficiency in the construction industry has caused many problems for projects' three constraints of time, cost, and scope, thus creating a BIM framework will reduce the error levels significantly [12,38]. Furthermore, a case study in the UK concluded that many construction organizations using a BIM tool ranked training and previous experiences with the technology higher as a CSF, which indicates that a better understanding of BIM implementation requires adding team members with prior experience and existing know-how on the subject matter [13]. On the other hand, ref. [2] utilized [12] CSFs in interviews with professionals from Hong Kong and found that they all supported the CSFs obtained from the latter. Yet, the perception of CSFs differed for top management support as an indicator of successful BIM implementation.

Many CSFs have been identified as human-related, industry-related, project-related, policy-related, and resource-related [12]. In addition, as previously noted there are limited to no studies conducted on the CSF for BIM implementation from a sustainability perspective. However, ref. [30] explored the available relevant literature on sustainability with BIM and noted the significance of integrating the former with the latter as a tool to reach the goal of sustainability. As such, BIM itself was described as a tool to pursue the goal of sustainability, but apart from this tool was the project life cycle holding potential added value in pursuit of sustainability; thus, life cycle assessment requires further research to uncover the potential significance [30]. In the literature, many CSFs have been identified for the effective and successful implementation of BIM in the construction industry. Yet, no CSFs specifically applicable to BIM implementation as a sustainability practice have been found. Table 1 demonstrates the selected CSFs from the literature review, defined and grouped according to the aim of this paper.

1.5. BIM in the UAE Construction Industry

With BIM, the construction sector has a method to increase productivity and revenue because using BIM in a particular building industry sector facilitates better decision-making overall [29,39]. Likewise, a study by Venkatachalam [40] concluded that the UAE construction industry relies heavily on BIM to create sophisticated, sustainable infrastructure. Nevertheless, Venkatachalam [40] also stated that the United Arab Emirates stands behind advanced countries, such as the United Kingdom and the United States, regarding BIM implementation due to challenges with overcoming the hurdles to adoption. Moreover, Mehran [39] found a lack of BIM standards and understanding, and a reluctance to change to be factors in the United Arab Emirates' (UAE) slow implementation of BIM in the construction industry. As a result, the United Arab Emirates is still behind the curve in embracing and deploying BIM for improved productivity and efficiency.

According to Zaini et al. [41], the rising use of BIM is based on the promise of the technology to aid the construction sector in achieving greater levels of efficiency and productivity, hence improving profitability. Although the UAE has experienced rapid growth over the past 25 years, the building sector has remained at the heart of the country's development. After reviewing the literature on BIM implementation as a sustainable construction practice and its associated CSFs, there is a lack of knowledge in this context in the UAE. Therefore, this research aims to identify and prioritize the CSFs for BIM implementation as a sustainable construction practice in the UAE by fulfilling the following objectives: (1) identifying the CSFs for BIM implementation in the construction industry from LR, (2) categorizing the CSFs based on the sustainability triple bottom line (economic, environment, and social), and (3) prioritizing the CSFs for effective BIM in the UAE construction industry.

1.6. Identifying the CSFs through Literature Review

Through an extensive literature review, several CSFs for effective BIM implementation have been identified. Then, the CSFs relevant to our approach were categorized to reflect BIM implementation as a sustainable practice. Table 1 shows all the selected CSFs grouped into the three bottom line aspects of sustainability (i.e., economy, environment, and social) and information technology, given that it is software to be implemented.

In conclusion, the importance of this research lies in its focus on BIM implementation as a practice to achieve sustainability in the construction sector. It's evident potential impact on energy consumption, air pollution, and greenhouse gas emissions, can in turn significantly impact climate change. In addition, because both public and private construction industries are the focus of this research, the findings from this study will be helpful for a wide range of stakeholders, including policymakers and decision makers, engineers, contractors, designers, and managers, among others. This will allow BIM users and stakeholders to regulate and implement practices that support overall sustainability in the construction industry. This is the first study to the best of the authors' knowledge, that identifies and prioritizes the CSFs for BIM implementation as a sustainable construction practice in the UAE and examines their ranking and relationships based on the triple bottom line (TBL). This aligns with the strategic direction the UAE is taking toward sustainable development.

Table 1. Critical success factors for BIM Implementation.

Category	Critical Success Factor	Definition	References
Social	Change management	Signifies how an organization has developed methodologies for changing its business processes and managing and changing people within the organization when introducing a new or modified process.	[6,13,42,43]
	Culture	Indicates how an organization's environment and the disposition of the people is orientated to learning and implementing something new.	[2,6,12,32,42–49]
	Effective communication among stakeholders	Effective communication and collaboration with clients during the process of implementation.	[6,7,12,13,42,44]
	Availability of competencies and interpersonal skills	Competent employees within the organization and the need to equip them with the necessary information and skills.	[12,50–56]

Table 1. *Cont.*

Category	Critical Success Factor	Definition	References
Environmental	BIM strategy and policy	Existence of an organizational strategy and policy on BIM implementation that supports the environmental aspect of sustainability.	[2,6,12,13,44]
	Environmental awareness within the industry	Existence of awareness and knowledge on BIM implementation and its positive impact on the environment.	[12,13,57]
	Higher understanding of sustainable practices	To promote sustainable practices such as BIM within the organizations.	[7,58–60]
	Predictive analysis of performance and simulation (energy analysis, e.g., CO_2)	The use of BIM will predict performance in terms of the environmental parameters and aid in negative impact reduction.	[7,59–62]
Economy	Employee education and training	Providing the employees with the required knowledge and skills for BIM implementation via extensive training programs, seminars, and workshops.	[2,6,12,13,42,44,53,56,58,62–64]
	Top management support and effective leadership	Top management commitment to implementing BIM through enabling resources and funds.	[2,6,12,13,42,44,54,65]
	Resource availability	The organization's ability to allocate an adequate budget for implementing BIM.	[6,12,13,54]
	Outsourcing	This refers to the practice of employing consultants in order to supply operational guidelines, knowledge structures, skills, and supervision for the purpose of ensuring a successful implementation process for BIM.	[6,7,12,13,42,66]
Information Technology (IT)	Appropriate hardware compatibility	Organizations should focus on the availability and maintenance of up-to-date technology hardware.	[6,42,51,52,67–69]
	Appropriate software compatibility	Organizations should ensure the software's availability and compatibility to operate together.	[2,6,12,42,51,61,68,69]
	Information sharing protocols	The availability of knowledge sharing and shared platforms in the industry.	[2,6,12,42]
	IT capabilities and availability of technical support	The availability and capability of IT technical support for BIM implementation within the organization.	[31,47,58,70–72]

2. Materials and Methods

This section presents the study's methodological approach. Figure 1 illustrates the holistic approach to the methodology of the study.

The process started from identifying the research gap to reaching the goal of the research, which involved identifying and prioritizing the BIM implementation CSFs. To prioritize the CSFs for BIM implementation in the UAE, an AHP pairwise comparison questionnaire was compiled. Based on the literature review conducted, 16 of the most cited CSFs were selected as sub-criteria and then categorized as one of the three bottom line sustainability pillars. Additionally, information technology criteria were added because of the importance of these criteria when identifying the CSFs for BIM, which will be elaborated on in the coming section. The data collection phase was conducted in two phases. The first preliminary phase was to gather all the critical success factors through a literature review. The second phase obtained data through a questionnaire.

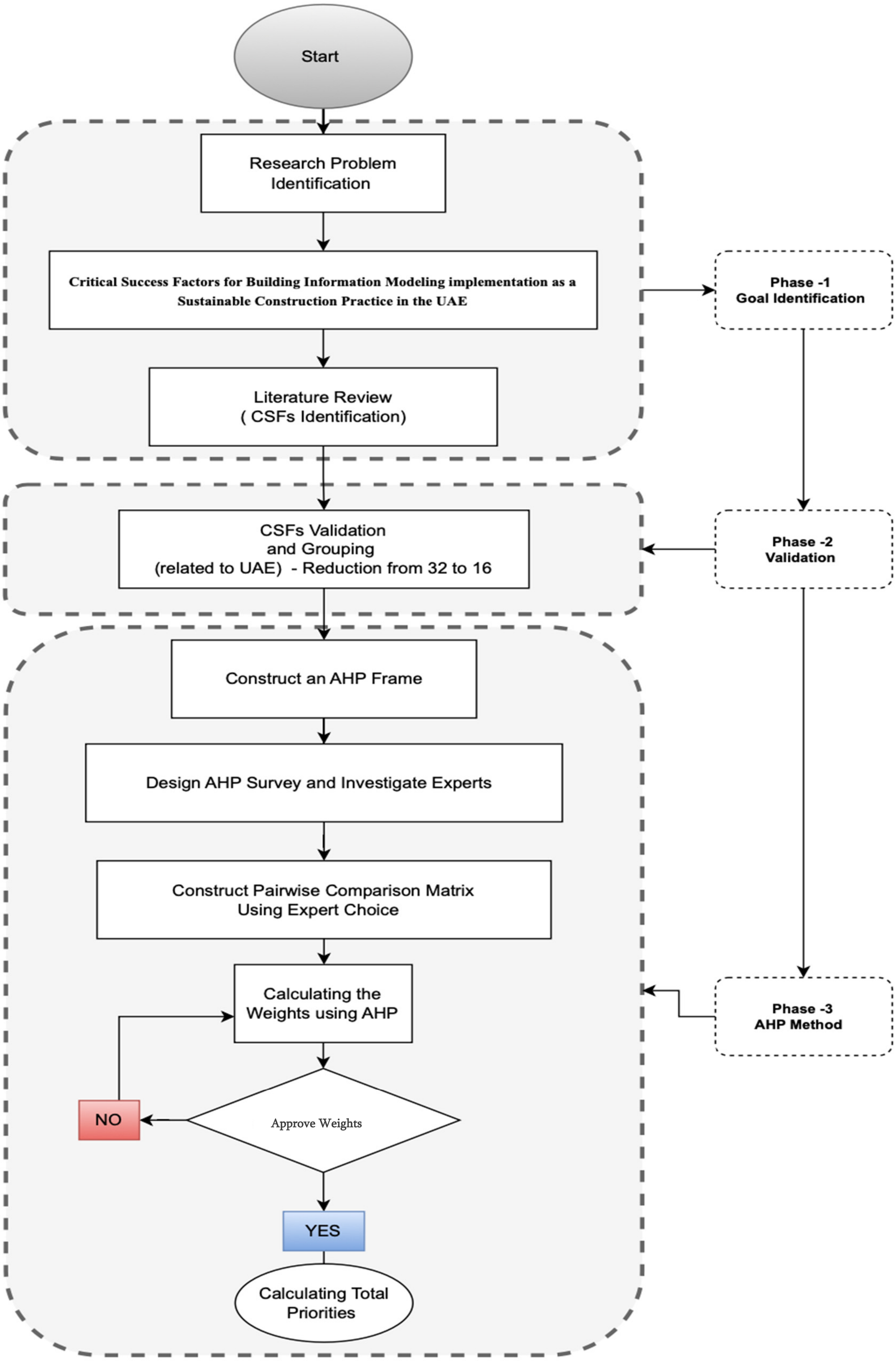

Figure 1. Methodology conceptual framework.

2.1. Study Area and Data Collection

The study was undertaken in the UAE and targeted both the governmental and private construction sectors. A one-round online survey consisting of seven sections was adopted to facilitate the access to experts. The period for the data distribution and collection was over three weeks. A total of 62 responses were obtained from one round of surveys by subject experts in the field. However, only 36 completed responses were retained for further analysis.

According to [73,74], choosing a statistical sample size involves numerous factors, like the constancy of specialists' education and experience in the field. According to AHP research in management and engineering, there is no minimum sample size that is necessary for AHP analysis [75–77]. On the other hand, it is feasible to generate a preference model that is closer to reality if as many experts as possible are consulted [78].

2.2. Analytical Hierarchy Process (AHP)

There are several methods that could be used to solve multicriteria decision-making problems (MCDMs), such as AHP, order TOPSIS, ELECTRE, and multi-objective programming [74,79,80]. AHP, which was first developed by Saaty in 1977, linearly weighs qualitative and quantitative factors. AHP integrates experts' opinions and evaluation scores into a simple elementary hierarchy system by decomposing complicated problems from higher hierarchies to lower ones. There are four steps in this modelling procedure: defining the decision problem, collecting relevant data, applying normalized weights, and obtaining a solution [81].

In this study, AHP was chosen as the method of preference for prioritizing the criteria and sub-criteria based on the experts' opinions. Several studies have found that the AHP technique is more suitable than other types of MCDMs due to its many benefits, including demonstrating how shifting priorities at higher levels can affect the importance of elements at lower levels [82,83]. Another advantage of choosing AHP is the utilization of the consistency measure, which improves the learning experience for decision makers [75,84,85].

The factors selected for the AHP model were compared as binaries to decide the significance according to a higher level component through pairwise comparison. The AHP model typically employs a 1–9 scale, created by Saaty in 1980 [86], to express the relative significance, with 1 denoting moderately important and 9 denoting tremendously essential. Saaty's AHP pairwise comparison importance scale is illustrated in Table 2 [86].

Table 2. Saaty's 1980 AHP pairwise comparison importance scale. Adapted from [86].

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored, and its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed

In this study, the expert's weight of importance was unknown. Aggregation of the responses from the experts was implemented using the weighted geometric mean method [87,88], an example of the individual expert results before aggregation is illustrated in Appendix A. According to [89], when the AHP uses the aggregation of individual judgments (AIJ), the weighted geometric mean method (WGMM) is the proper statistical technique to utilize. A weighted form of the geometric mean of n definite positive matrix can be determined through the WGMM. In this method, the weights are calculated differently for each n-dimensional positive probability vector [90].

In group decision-making, the WGMM is commonly used for attaining a group judgment in AHP [91]. According to [74,92,93], the weighted geometric mean of n positive definite matrices $A1, A2, \ldots, An$ with weights $w1, w2, \ldots, wn$ is given by Equation (1) [74]:

$$(A1\hat{}(w1/sum(w)))\hat{}(1/sum(w)) * (A2\hat{}(w2/sum(w)))\hat{}(1/sum(w)) * \ldots * (An\hat{}(wn/sum(w)))\hat{}(1/sum(w)), \quad (1)$$

2.3. Consistency Ratio for Criteria and Sub-Criteria

The consistency ratio (CR) was calculated to justify the consistency of the comparisons provided by the Sharjah citizens in the pairwise comparison matrix. The comparisons in the pairwise comparison matrix are considered consistent if the CR is equal to or less than 0.1 [94,95]. The CR was calculated using the following Equation (2) [74,86]:

$$CR = Consistency\ Index/Random\ Index \quad (2)$$

where random index (RI) represents the randomly generated average consistency index, and the CI [94,95], which is defined by Equation (2) [74,86,96]:

$$CI = (\lambda max - n)/(n - 1) \quad (3)$$

where λmax refers to the largest eigenvalue in the matrix and n represents the order of the matrix [97]. Table 3 shows the value of the random index sorted by the order of the randomly generated pairwise comparison matrix [74,86,96].

Table 3. Average random consistency index (RI). Adapted from [86].

Order Matrix	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0.00	0.00	0.58	0.90	1.12	0.24	1.32	1.41	1.45	1.49

Once the pairwise comparison matrices have been constructed, the weight of each decision element can be calculated using standard AHP computation. Then, a consistency ratio was obtained for the consistency of the results. In this study, an AHP three- level hierarchy model was built according to the relationship between the goal, the main criteria, and the sub-criteria, as shown in Figure 2.

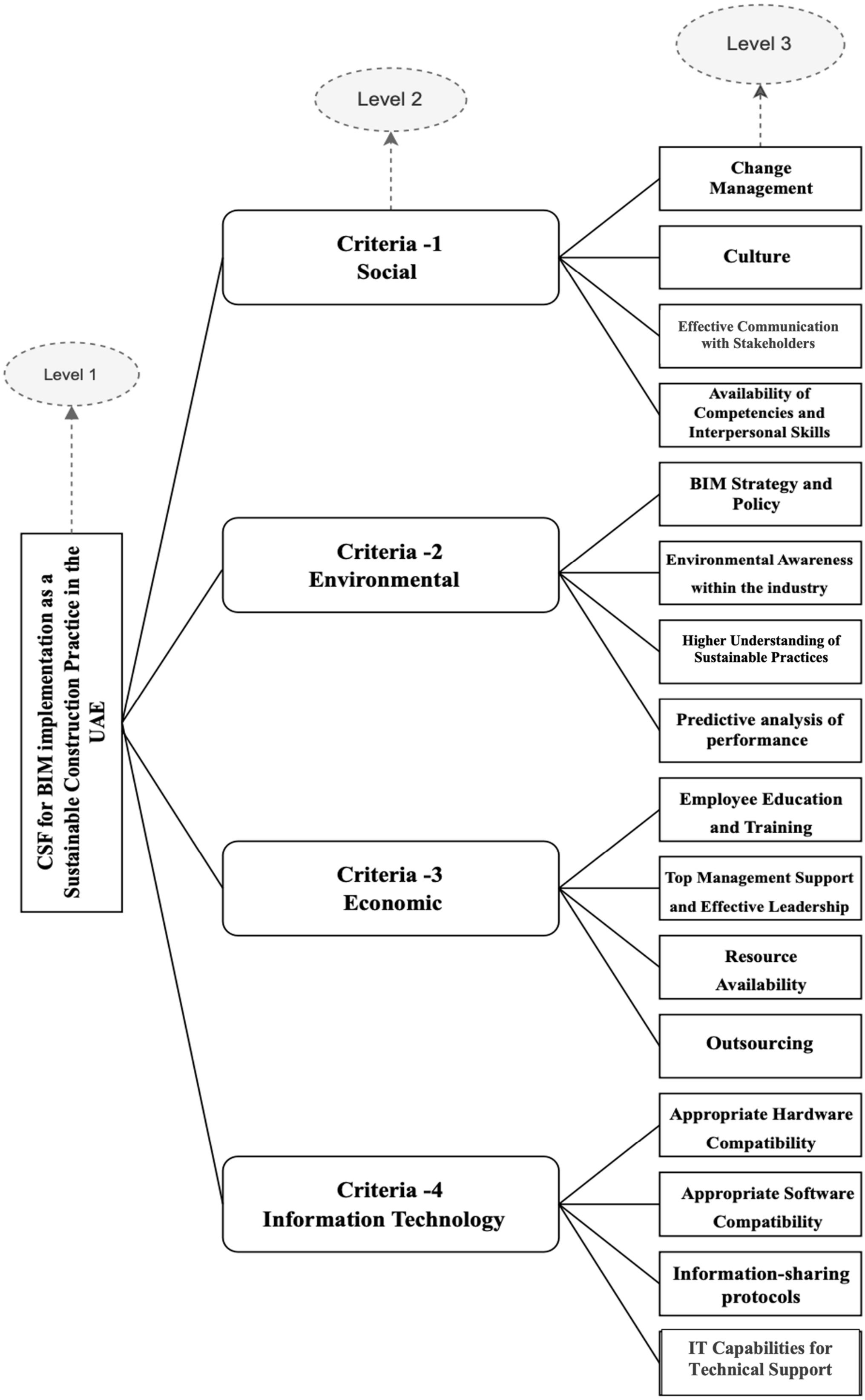

Figure 2. AHP hierarchy conceptual model. Source: Authors.

3. Results

Following the literature review, several CSFs for effective BIM implementation were identified, and the relevant CSFs in the context of the study were selected, as shown in Table 1. The CSFs were then categorized based on the objective of this study, which was implementing BIM as a sustainable practice in the construction industry. A pairwise comparison questionnaire was developed targeting the subject matter experts (SMEs) in the construction industry. The data from the questionnaire was used to serve the aim of the AHP analysis, prioritizing the selected CSFs for BIM implementation as a sustainable practice.

3.1. Respondents' Demographic Information

Different SMEs from different employment levels (5% entry level, 20% analyst, 55% managerial level, and 20% C-suite level) responded to the questionnaire, such as BIM managers, BIM architects and engineers, and project managers who had experience with BIM. In terms of the organizational sector, 55% of the responses were from the private sector and 45% of the responses were from the public sector. Moreover, the questionnaire showed that 55% of the SMEs have 11–20 years of experience, whereas no SMEs with less than five years' experience were included. Regarding the respondents' role in the construction industry, the result showed that around 21% were contractors, almost 36% were consultants and engineers, 15% were construction managers and almost 27% were clients. The respondents' demographic information is shown in Figure 3a–d.

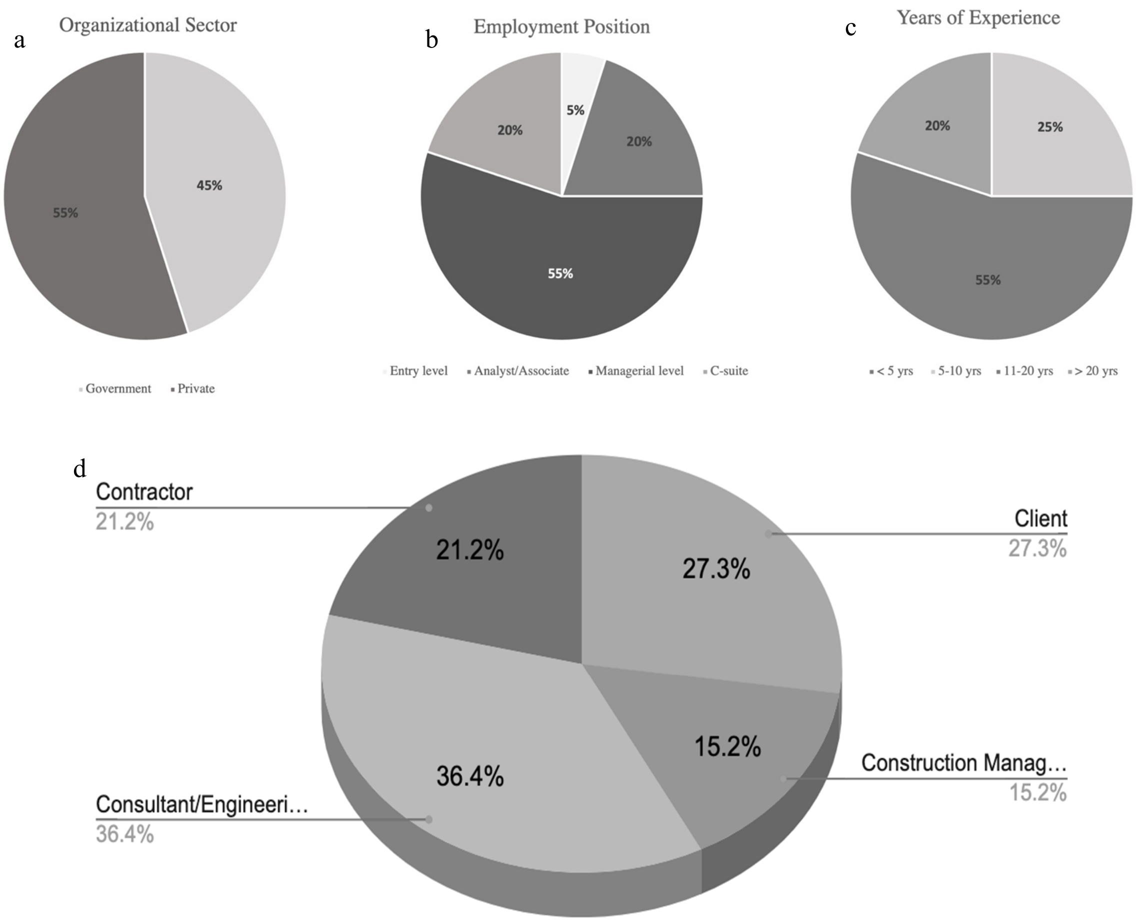

Figure 3. Demographic information: (**a**) organizational sector, (**b**) employment position, (**c**) years of experience, and (**d**) their role in the construction sector.

3.2. Consistency Ratio for All the Criteria

The consistency ratio for all the criteria are listed in Table 4. All the consistency ratios are less than 0.1. So, all the criteria are consistent to create the overall weightage for the AHP analysis.

Table 4. Consistency ratio for all the criteria.

Main and Sub-Criteria	Consistency Factors	Consistency Ratio	Consistency Index	Lambda Max	Random Index
Main criteria	Economic Social Environmental Information Technology	0.005	0.00518	4.01554	0.9
Economic	Employee education and training Top management support and effective leadership Resource availability Outsourcing	0.100	0.09572	4.28715	0.9
Social	Change management. Culture Effective communication among stakeholders Availability of competencies and interpersonal skills	0.057	0.05183	4.15548	0.9
Environmental	BIM strategy and policy Environmental awareness within the industry Higher understanding of sustainable practices Predictive analysis of performance and simulation (energy analysis, e.g., CO_2)	0.102	0.09202	4.27605	0.9
Information Technology	Appropriate hardware compatibility Appropriate software compatibility Information sharing protocols IT capabilities and availability of technical support	0.01804	0.01624	4.04871	0.9

3.3. AHP Analysis Results: Global and Local Weights

After comparing the consistency ratio analysis, the weights of the main criteria and their respective sub-criteria were multiplied to create the overall global weights. The overall global weights were multiplied by 100 for calculating the percentage of every sub-criterion [86]. A pairwise comparison matrix was used for the four main criteria: economy, social, environmental, and Information Technology (IT), followed by a comparison of the sub-criteria against each other for all the 36 responses based on Saaty's [86] scale, as shown earlier in Table 2. To determine how much each element contributed to each criterion, the method for geometric averages was utilized as the measuring tool. According to the information found in [77,85], in order to calculate the global weight vector, this method takes into account both the priority weights of the criterion and the local weights of the alternatives. This is due to the fact that both the local weights and the priority weights are derived from pairwise comparison matrices that are provided by a decision maker in accordance with their own judgment. Table 5 presents the percentage of every sub-criterion weight.

Among the main criteria, the social aspect ranked the first, weighing 31%, followed by "economy" at 29%, "environmental" at 21%, and "IT" at 20%. Concerning the sub-criteria, effective communication among stakeholders under the social criterion ranked first with a global weight of 11%, followed by top management support and effective leadership under economy, weighing 10%. The last ranked sub-criterion was outsourcing under economy, weighing 3%. The obtained global weights for the criteria and sub-criteria from the AHP analysis are listed in Table 5, with the rankings.

Table 5. Calculated weights from AHP analysis for all the criteria and sub-criteria.

Criteria	Rank (%)	Sub-Criteria	Local Weights (%)	Global Weights (%)	Global Rank
Economic	28.56	Employee education and training	35.15	10.04	3
		Top management support and effective leadership	35.49	10.14	2
		Resource availability	20.35	5.81	9
		Outsourcing	9.00	2.57	16
Social	30.88	Change management	25.44	7.86	4
		Culture	19.57	6.04	8
		Effective communication among stakeholders	34.79	10.74	1
		Availability of competencies and interpersonal skills	20.20	6.24	6
Environmental	20.92	BIM strategy and policies	27.55	5.76	10
		Environmental awareness within the industry	31.83	6.66	5
		Higher understanding of sustainable practices within the organization	26.54	5.55	11
		Previous experiences in predictive analysis and simulation	14.08	2.95	15
Information Technology (IT)	19.64	Appropriate (hardware) compatibility	31.57	6.20	7
		Appropriate (software) compatibility	23.88	4.69	12
		Information sharing protocols	21.46	4.21	14
		Availability of technical support	23.09	4.53	13

4. Discussion

Over the past years, there has been a rise in demand for the effective implementation of BIM in the building and construction sectors. Several studies have found CSFs for BIM, which are criteria that can be used to support successful BIM implementation in an organization. Although several studies have tackled this issue, none of them have focused on the CSFs that are associated with sustainable TBL. To obtain accurate results, researchers must use solid and valid procedures. This may involve choosing study strategies, sample procedures, data gathering and processing methodologies, and statistical tests. BIM deployment is context specific. Thus, researchers must account for diverse construction projects' unique problems and potential. The questionnaire was used to serve the aim of the AHP analysis, prioritizing the selected CSFs for BIM implementation as a sustainable practice. BIM subject matter experts from the private (55%) and public (45%) sectors from different employment levels (5% entry level, 20% analyst, 55% managerial level, and 20% C-suite level) responded to the questionnaire to represent the different types of construction projects dealing with BIM. The following section will investigate the obtained results and explain the study's practical and theoretical implications.

4.1. Main Criteria

The results from the AHP analysis show that the social aspects were ranked the highest compared to the other criteria, with a weight of 31%, followed by "economy" at 29%, "environmental" at 21%, and "Information Technology" at 20%. This is an intriguing initial result. The literature review focused on the technical aspects of BIM implementation and less on the social aspects as most have considered this tool to be a programable software. Therefore, to a certain extent, this finding confirms [12]'s statement that human integration with any systematic framework has a significant impact on the success of machine learning; otherwise, it would only be inputs and outputs without intelligence. Then, the economic aspects were found to be the second most important success criteria, which is due to the impact that BIM contributes towards the optimization and reduction of cost and time when implemented in the construction industry, as these two measures are essential resources to define the success or failure of projects. Nevertheless, the economic aspect is a crucial driver for stakeholders and top management to support the construction project's success and utilize the available human resources to operate within the BIM framework. The third and fourth ranked success criteria were the environmental and IT aspects, respectively. These two criteria, even though they are considered a vital part of the BIM system, were ranked lower by the subject matter experts because they are considered supportive criteria to the BIM implementation, as the environmental aspects are mainly thought of in terms of the impact that will be realized after the successful implementation of BIM.

In contrast, IT represents the primary support and available tools for operating the BIM system. It was expected that IT would rank as playing a vital role in implementing BIM. Surprisingly, the current study does not show that the IT criterion is as vital as the economic or the social parts.

Furthermore, the study's confirmed findings prove beneficial for researchers to identify the key determinants contributing to the uptake and diffusion of BIM technology in the construction industry. The acquisition of this knowledge can contribute to a theoretical comprehension of the technology acceptance and dissemination process within the construction industry. Additionally, it can guide the creation of green strategies and policies that support the sustainable construction sector.

4.2. Social Aspect

The social aspect was ranked the highest amongst the major criteria. Within this criterion, it was found that effective communication among stakeholders is the most important with a global weight of 11%, as the subject matter experts feel that it is imperative to have buy-in from all or most of the construction project stakeholders to achieve the strategic goal of implementing BIM. This is affirmed by the findings of [15], that the social factors and organization culture toward change management play an important role in the effective implementation of BIM. It is vital for the project that the information within a project that implements BIM is circulated and communicated effectively. Any misinterpretation of such information is attributable to the human factor rather than the BIM framework as it is used as a tool rather than as a thinking machine. Therefore, this factor is found to globally rank the highest within the whole AHP analysis. Next was changing management, which was ranked second within the social aspect. One can interpret, as in human nature, that resistance is a natural response to the introduction of new technology, such as BIM or a change within the system itself, by human operators, thus creating issues for dealings amongst the project team as well as among the hierarchy of workers within the implementing organization; therefore, potentially creating more problems rather than optimizing a solution. This is affirmed by the findings in [6], that BIM is a process that will create more problems than those anticipated as it involves many systems and operations within the process and, as such, will require proper resilience within the organization to adapt to such changes, which is in agreement with this study's findings.

The interpersonal skills and competencies in the project team were ranked third in terms of importance within this criterion, as the BIM framework is considered a unique organizational asset that must secure highly skilled operators within the system to be competitive in the market. Accordingly, this was considered in context with the economic aspect of this study. The organization's investment in human resources is to be considered an asset that contributes massive value to the organization's strategic goals in implementing BIM. Although culture was ranked fourth within the social aspects, this has a vital impact on BIM implementation, as well as being vital in relation to the previously discussed success factors. The organization's culture is a significant factor for the success or failure of any project that utilizes BIM technology, as the resistance or acceptance of such technology or process will require approval from the stakeholders who might be the project team, BIM team, investors, organization leadership, etc. According to [43], culture is an important part of the organization, which defines the environment and its ability to adapt to new processes and procedures, according to the strategic plan communicated by the organization's leadership. Therefore, from the global weightage perspective, the social aspect CSFs were considered the top ranked among the other CSFs. Thus, a higher ranking was obtained for this significant criterion.

4.3. Economic Aspect

Ranked as the second CSF criterion, the economic aspects of the BIM implementation were found to be the highest ranked success factors: top management support and leadership, and employee training and education. Both of those factors were considered to be very important by the SMEs due to their value to the organization where the BIM system is being implemented. The leadership support and the organization's employees must have the knowledge and skills that leads to the successful use of the BIM technology and to support the organization's strategic objectives for the full adaptation of the technology. This conforms with [6,13], which found that extensive training and development is necessary to achieve the highest quality in BIM implementation, as well as the possibility to invest in the organization's resources rather than relying on outsourcing, which would then be a loss to the competitive advantage. Therefore, it is noticed that resource availability was considered the third most important CSF amongst the economic aspects, considering that human resources are a vital element in the success of any organization. In contrast, the outsourcing of equipment and BIM operators were considered the least important, even on the global scale, weighing 3%, as it is considered harmful to the organization that wishes to successfully implement BIM in its strategic projects, thus jeopardizing the competitive advantage and losing some of its market share to its competitors. This is mainly since the outsourcing of operators and equipment could be used against the organization if the outsourcing specialist were to share the acquired knowledge and skills learned from the previous organization with another, which would benefit from the issues and problems raised and solved during the project, therefore saving time and money for the competitive organization, thus obtaining higher ground in the turbulent market area. Therefore, one must be careful when dealing with new technologies and aim to achieve higher standards that will benefit one's own investment rather than sharing information with others in the same market atmosphere.

4.4. Environmental Aspect

The environmental aspects were ranked third amongst the significant criteria of the success factors, yet it was also close in weightage to the IT criterion. This is due to the realization by the SMEs that the environmental aspects within the construction industry are not realized immediately or do not have an immediate impact, since the process implementation consists considerably of new technology and requires a lot of observation and study. Moreover, it was noticed from the reviewed literature that this subject within the BIM verse is yet to be appreciated, as it has no metrics that can measure its effect either in the shorter or longer run. When it comes to the success factors within the environmental aspects, it is immediately noticeable that environmental awareness within the construction industry is ranked highest; where this is obvious as the construction industry is considered one of the highest polluting industries in the world, as mentioned by [17,18]. Therefore, environmental awareness has evolved over the years. Many municipalities around the world implement the highest environmental standards to reduce the negative emissions from the construction industry. Although environmental awareness is considered an essential factor when implementing BIM, it is worth mentioning that BIM's embedded benefit is to reduce errors within the building or desired construction model, which will have an impact on the wasted materials or variations that can be realized in the model itself prior to implementation on the site, which reduces any reworks and, accordingly, the waste of resources. Although realizing that the awareness of the environmental aspects within the industry is important, the rest of the success factors, namely BIM strategies and policies, a higher understanding of sustainable practices within the organization, and previous experience of predictive analysis and simulation were ranked lower in importance, due to non-significance. As mentioned earlier, those environmental aspects are still not well understood and prioritized within the context of the BIM verse; thus, specialized studies need to be conducted to understand further the environmental implications.

4.5. Information Technology (IT) Aspect

The IT criterion was ranked last. This is mainly since IT is an integral part of the BIM system, which must be operational within the project environment and integrated with other project management systems. However, it is evident from the AHP analysis that only hardware compatibility is ranked higher among the CSFs for IT, which is attributable to the need for a higher capacity of machines to process the different data from multiple sources as the root of the BIM technology. Although software compatibility is also an integral part of the process, the SMEs gave higher importance to the hardware since the capacity of the hardware contributes directly to the smoothness of the software running the programs and the data accumulation, analysis, and modeling, which corresponds to the findings of [13,42]. The rest of the IT CSFs were considered insignificant by the SMEs, this might be due to the supporting nature of the IT within the BIM verse, such that considerable impact is shifted toward the social and economic aspects rather than the environmental or IT aspects.

4.6. Overall Rating (Global Weights)

Several notes obtained from the global weightage indicate the CSFs for BIM implementation. As mentioned earlier, effective communication among stakeholders was ranked the highest in terms of importance by the SMEs, attributable to the social aspects. In contrast, the second and third-ranked were top management support, and employee education and training, attributable to the economic aspects. Therefore, it is understood that the stakeholders and the human factors within the BIM frameworks and their related processes significantly impact the success of BIM implementation within the project's setup. This was confirmed by previous studies, such as [5,14,15], which implies that a proper BIM framework does not operate appropriately without adequate integration of the anthropogenic elements that can withstand the errors in the systems' operability. Therefore, IT CSFs were ranked the lowest among all the CSFs as 11th, 14th, and 15th out of 16 criteria in the global weightage. In contrast, the outsourcing part of the economic criteria obtained the lowest ranking of the CSFs, which is indirectly related to IT as support from outside the organization. Finally, the SMEs questionnaire showed higher consistency for all the criteria obtained from the literature, which can reflect on the industrial context within the construction project management, thus providing a view on the advanced technology utilization within the construction industry and help to develop and harness the integration management tools and techniques.

5. Conclusions and Future Work

To address the knowledge gap linking BIM to sustainable construction, this research aimed to identify and prioritize the critical success factors for the implementation of BIM as a sustainable construction practice in the UAE. These critical success factors reflect on how to achieve successful BIM deployment by maximizing the benefit to the industry by achieving the strategic objectives.

Prioritizing the CSFs in BIM implementation can provide academics with an enhanced comprehension of the elements that facilitate the effective integration of BIM in construction undertakings from a theoretical standpoint. BIM technology can aid researchers in identifying the primary factors that impact the adoption and diffusion of this technology in the construction sector. The aforementioned knowledge has the potential to enhance the efficacy of implementation policies and strategies and augment the theoretical comprehension of technology adoption and diffusion within the construction industry.

Furthermore, limitations in research can differ based on the type of research conducted. In this study, the time constraints and access to experts were the most challenging parts accrued during the data collection and analysis phase. This led to using an online survey form and following up with the experts over three weeks to ensure the quality and reliability of the research.

This study is considered a benchmark for future works in the field of BIM implementation. It is worth mentioning that the results in the study were obtained from experienced BIM stakeholders, who have experience working with BIM implementation processes, which means that the obtained weights and the importance of the CSFs can be utilized to establish a framework that can be used to improve the implementation of BIM in sustainable construction projects, by using the findings checklist on CSFs for implementing BIM effectively. Furthermore, the performance of the BIM implementation can also be measured by the project's stakeholders using the level of the CSF's success during the project's lifecycle. In addition, stakeholder management theory in BIM-enabled projects has an opportunity to have a positive impact not only on the project's execution but also on its overall performance. It has the potential to provide researchers and practitioners with insights that can be used to conduct additional empirical studies in the future.

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Appendix A. AHP Expert Sample Result before Aggregation

Main Criteria

R1	M1	M2	M3	M4
M1	1	9	1	1
M2	1/9	1	1/9	1/9
M3	1	9	1	1
M4	1	9	1	1

Economic

*R*1	*C*1	*C*2	*C*3	*C*4
*C*1	1	7	1/7	7
*C*2	1/7	1	9	9
*C*3	7	1/9	1	1/7
*C*4	1/7	1/9	7	1

Social				
*R*1	*C*5	*C*6	*C*7	*C*8
*C*5	1	1	1	1/6
*C*6	1	1	7	1
*C*7	1	1/7	1	1/8
*C*8	6	1	8	1
Environmental				
*R*1	*C*9	*C*10	*C*11	*C*12
*C*9	1	1/7	1/8	1/8
*C*10	7	1	1/9	1/9
*C*11	8	9	1	1
*C*12	8	9	1	1
IT				
*R*1	*C*13	*C*14	*C*15	*C*16
*C*13	1	1	8	1
*C*14	1	1	8	1
*C*15	1/8	1/8	1	1/9
*C*16	1	1	9	1

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