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Original Article

Factors Affecting the Optimization of Design and Construction for Sustainable Building Using Value Engineering in Egypt

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Abstract - *This study aims to enhance the performance and practices of workers in construction projects in Egypt through sustainability and value engineering. A list of key factors influencing the optimization of the design and construction of sustainable buildings using value engineering in construction projects in Egypt was identified across both the public and private sectors. Previous studies were reviewed, and experts in the field were interviewed. Subsequently, a questionnaire survey was conducted with 385 specialists in the construction industry who possess expertise in sustainable design, construction, and value engineering. Statistical analysis was then conducted, which led to the conclusion that the most critical factors for the design stage were the application of value engineering requirements during the early stage of sustainable design, providing alternatives and suggestions for sustainable design to achieve optimal project cost, applying LEED and design requirements, and their impact on cost and value engineering requirements. The most critical factors for the construction stage are reducing construction material emissions, renewable and clean energy source use, monitoring water consumption performance, preparing a plan for waste management of construction and demolition, and continual communication between management workers and correcting unsafe practices. The suggested measures to address factors that affect the optimization of design and construction for sustainable buildings using value engineering in Egypt include a thorough examination of contract documents at the tender stage, effective coordination, and diligent monitoring by all parties involved throughout the design and construction phases.*

Keywords - *Sustainable Design, Sustainable Construction, Value Engineering, LEED, Egypt.*

1. Introduction

Achieving optimal performance is crucial, and construction projects will likely encounter various challenges during delivery [1]. Numerous researchers in the field of project management have investigated the key factors that are essential for project success. Sustainable construction is often defined as a process that begins prior to actual construction (during the planning and design phases) and extends beyond the departure of the construction team from the site [2]; on the other side, Value Management (VM) is a structured, function-focused, systematic team strategy aimed at evaluating the functions and expenses of a system, supply, equipment, service, or facility. The goal is to improve its value by meeting the specified client functions at the most cost-effective rate possible while maintaining performance standards [3]. Various studies have highlighted the critical importance of addressing the environmental dimensions of construction sustainability to enhance the quality of building operations. While the environmental aspect has been extensively studied, there is increasing recognition of the growing significance of the social aspect in sustainability discussions [4]. Academics of project management have also addressed this topic. Researchers have examined and assessed sustainability across various project management contexts, highlighting it as a significant issue and challenge in new product development, infrastructure, energy, mining, and construction [5]. The advantages of incorporating sustainability into the project management plan were described as follows: "In the construction industry, sustainability aims to achieve a win-win scenario by enhancing the environment and advancing society while also providing competitive edges and economic benefits to construction companies" [6].

In developing countries, the sustainability of building projects requires a back seat. With rapid development in these nations, it is undeniable that the building industry plays a critical role in providing essential living spaces [7]. The Society of American Engineers defined Value Engineering (VE) as the use of cost-effective techniques to evaluate the functionality of a product or service by removing unnecessary

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expenses and enhancing the value delivered in public projects. On the other hand, Abdul-Aziz highlighted the importance of the human factor in VE's success, asserting that teamwork should thoroughly assess project benefits to deliver solutions that not only meet but surpass customer needs [8]. Value Engineering (VE) should be recognized and comprehended at every project stage. As one of the available approaches for designers and VE teams, its application is crucial for ensuring that projects achieve whole-life values [10]. VE has proven to be a highly effective approach for delivering enhanced values by analysing project requirements to fulfil basic functions, as shown in Figure 1 [11].

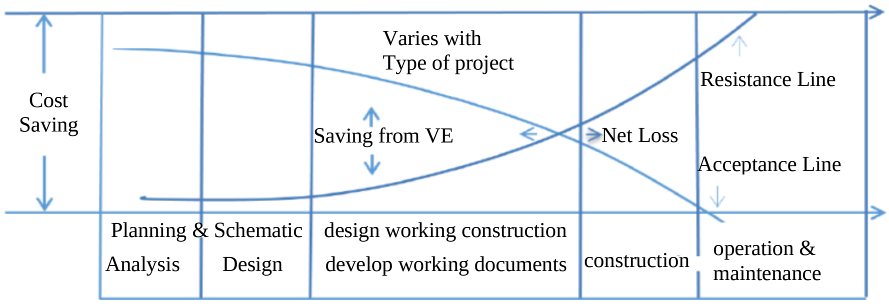

Fig. 1 The implementation of Value Engineering (VE) offers the potential for significant cost savings [11]

2. Literature Review

Numerous studies have aimed to identify key success factors in the construction industry. Research has shown that defining a project as successful or unsuccessful can be challenging because of the varying interpretations of success and failure among project participants. To address this issue, we conducted a literature review to gather diverse perspectives from various researchers. Scholars have conducted extensive research to capture critical success factors in construction projects. The push for sustainable development and the integration of innovative corporate social responsibility practices by companies serve as motivators that could also promote the utilization of Value Management (VM) during the initial strategic stages of construction projects [9]. Incorporating Value Engineering (VE) into the sustainable design of construction projects is advantageous for reducing the negative impacts of construction waste on both the environment and finances. Construction waste can be divided into material waste and time waste, and VE serves as an essential tool for managing waste and designing projects that minimize waste generation. As noted in [12], the combination of Value Engineering and sustainable practices can be effectively integrated into a project without jeopardizing its future needs. Overall, VE is a crucial approach for fostering sustainable construction from the very beginning of a project. By aligning with the principles of sustainable development, VE helps maximize the value derived from projects. To ensure the success of sustainable construction projects within the integrated design process, it is essential to first identify sustainable attributes that can be integrated into a building during the design phase. The primary goal of the project is to stay within the designated budget while minimizing negative environmental impacts. Sustainable design elements are typically prioritized in the Value Engineering (VE) process unless they have already been incorporated through an integrated design approach [13]. During the workshop phase, VE plays a crucial role in developing sustainable design principles by providing decision-makers with various tools and techniques to make informed choices that generate value for multiple stakeholders in a project. The creative phase yields numerous alternatives to achieve objectives while steering clear of unsustainable studies on applying Value Engineering (VE), focusing on sustainability considerations to enhance project value [14]. The concept of sustainability is multifaceted; however, certain key concepts can be identified within core sustainability dimensions. The interlocking circle model effectively illustrates the necessity of integrating and balancing the three objectives, as illustrated in Figure 2 [15].

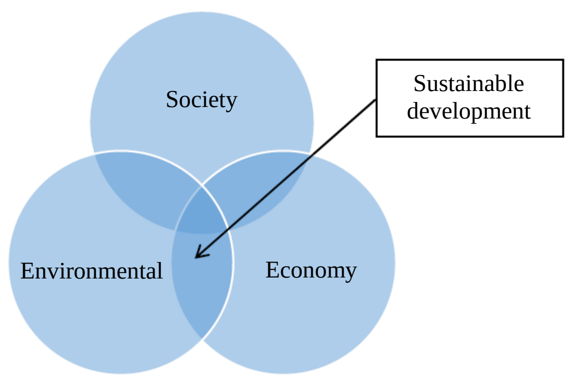

Fig. 2 Sustainable development scheme [15]

The estimated project savings resulting from the comprehensive VE analysis ranged from 20% to 30% of the element cost, leading to a substantial reduction in the total project cost. Value Engineering (VE) can significantly impact the sustainability of new facilities and the costs associated with building operations throughout their life cycle [16].

A case study was conducted to investigate this assertion by focusing on the perceptions of project managers and facility personnel regarding the influence of VE during the design and construction of new facilities. Data were gathered and analyzed through semi-structured interviews, leading to several important recommendations. The study revealed that applying Value Engineering (VE) during the design and construction phases of facilities enhances sustainability and lowers life-cycle costs. Additionally, integrating sustainable elements into the VE process results in greater life-cycle cost savings for new facilities. These findings highlight the necessity of incorporating VE and sustainability considerations in developing new facilities to realize long-term economic and environmental advantages. This research explored the fundamental factors influencing optimising sustainable building design and construction through value engineering in Egypt. To achieve this goal, a thorough survey was conducted among stakeholders in the Egyptian construction industry to identify and analyse the key factors impacting the optimization process. The sources of the construction factors were categorized into 27 factors, which were further grouped into two main categories: sustainable design and construction. These factors, along with relevant references, are listed in Table 1.

Table 1. Factors affecting the optimization of design and construction for sustainable building using value engineering through literature

CF Group	Code	Activity Name	Ref.
V.E. Factors to sustainable design	**VESD.1**	Apply value engineering requirements during the early stage of sustainable design.	[9]
	VESD.2	Providing alternatives and suggestions for sustainable design to achieve optimal project cost.	[18, 23]
	VESD.3	Applying LEED and design requirements and their impact on cost and value engineering requirements.	[17, 19]
	VESD.4	Energy efficiency in building design.	[19]
	VESD.5	Efficiency of the planning and design team, sustainability requirements and value engineering.	[17, 20]
	VESD.6	Study the impact of materials used in design on the environment.	[20]
	VESD.7	Study the specifications of the materials used in the project to meet the requirements of sustainability and value engineering.	[18]
	VESD.8	Reducing, reusing and recycling construction and demolition waste.	[23]
	VESD.9	Cost analysis during the project planning stage.	[20]
	VESD.10	Client influence/client representative (client paid for value engineering and sustainable construction requirements study).	[20]
	VESD.11	Preparing sufficient geotechnical studies before starting the design.	[23]
	VESD.12	Develop a plan to deal with accidents and emergencies.	[25]
V.E. Factors to sustainable construction	**VESC.1**	Reduce waste in construction materials.	[18]
	VESC.2	Storing materials methods to prevent the introduction of moisture and accumulation of dust.	[25]
	VESC.3	Preserve the raw materials used and reused.	[21]
	VESC.4	Reduce the construction materials emissions.	[22]
	VESC.5	Renewable and clean energy sources are used.	[24]
	VESC.6	Monitoring water consumption performance.	[21]
	VESC.7	Prepare a plan for waste management of construction and demolition.	[22]
	VESC.8	Easy manoeuvring for labour and equipment on site.	[26]
	VESC.9	Skilled labours during construction.	[25]
	VESC.10	Construction method and site management.	[24]
	VESC.11	Inspect equipment before construction.	[20]
	VESC.12	Energy savings/Reduced energy use.	[20, 24]
	VESC.13	Access to the site using mass transit.	[26]
	VESC.14	Continual communication between management and workers and correcting unsafe practices.	[26]
	VESC.15	A specialized engineer will be present to provide safety instructions on site.	[23]

3. Materials and Methods

To meet the research objectives outlined in the introduction and literature review, this study utilized a questionnaire survey to collect empirical data from construction professionals in Egypt. A thorough review of existing literature and interviews with industry experts was conducted as a preliminary step to identify the key factors that enhance the design and construction of sustainable buildings through value engineering in Egypt. This process identified 27 factors, which were then organized into two main categories: design and construction. These factors formed the basis of the survey instrument, which was distributed to stakeholders in

Egypt's construction sector. The questionnaire consisted of three sections: the first section provided a detailed overview of the questionnaire, its purpose, the required response method, and an assurance of confidentiality. The second section solicited general information, including name, educational qualification, field of work, position, and years of experience. The third section focused on the primary research objective, assessing each factor's impact level. The questionnaire targeted experienced Egyptian construction practitioners from various sectors, including owners, contractors, consultants, researchers, and academics.

Respondents were asked to rate the factors using a Likert scale with the following options: very low, low, medium, high, and very high. Upon completing the data collection, a statistical analysis was performed using SPSS version 20 to calculate the correlation between the 27 factors using Cronbach's alpha. In addition, the Relative Importance Index (RII) is employed to quantify the impact of each category. This enabled the development of a prioritized list of factors. The resulting prioritization is expected to inform sustainable construction management practices. Discussing the findings provides the industry with actionable recommendations grounded in the priority values assigned to each factor [31]. By adopting these recommendations, construction stakeholders can optimize their practices to mitigate factors and promote sustainability in the Egyptian construction sector. The research methodology was conducted in a systematic manner, as illustrated in Figure 3, to ensure the achievement of the research objectives.

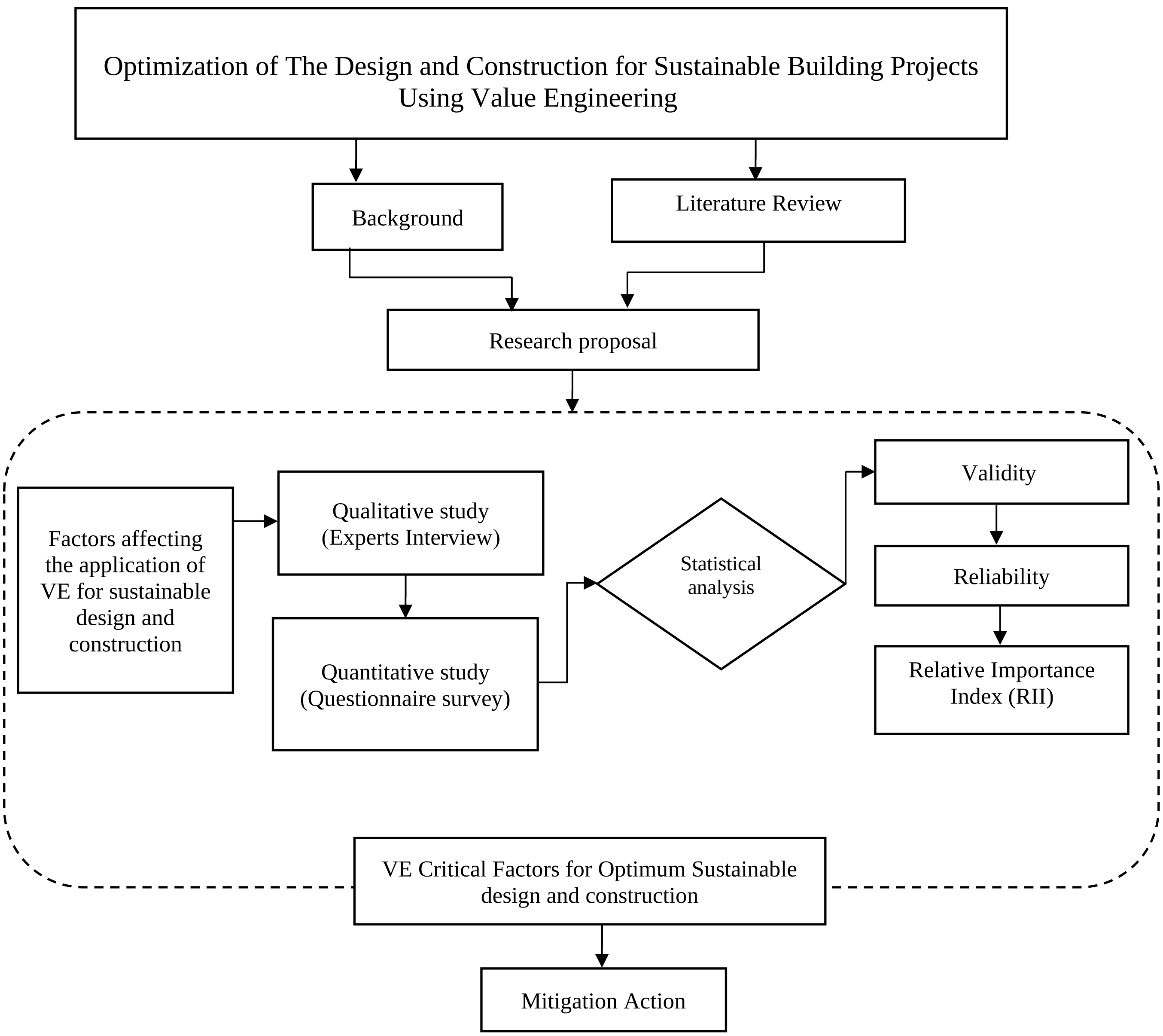

Fig. 3 Research flowchart

Participants were carefully selected to represent the Egyptian construction industry to ensure the validity and reliability of the study's findings. The sample size was determined using the Cochran equation recommended by Singh and Masuku [27] and Krejcie and Morgan [28].

With a confidence level of 95% and a margin of error of 5%, the calculated sample size was 385, which is suitable for a population of over 100,000. To reach the target sample size, the researchers collected information about consultant offices, construction companies, and owners working in the Egyptian construction industry, focusing on those familiar with sustainability and value engineering in both the government and private sectors. Respondents' profiles are presented in Table 2. A total of 437 questionnaires were distributed to achieve a sample size 385. However, 23 incomplete questionnaires were received, resulting in a response rate of 88.10%. This response rate was considered satisfactory for the analysis and deemed acceptable based on Hammam et al. [29]. The careful selection of participants and adequate response rate ensure that the study's findings represent the Egyptian construction industry and provide a reliable basis for factors affecting the design and construction optimization of sustainable buildings using value engineering in Egypt.

Table 2. Respondent demographics and background information

Item		Respondents (385)	
		Frequency	%
Level of Educational Attainment	PhD	18	4.67%
	Master's	33	8.51%
	Bachelor	334	86.82%
Area of expertise	Owner	63	16.36%
	Consultant	83	21.55%
	Contractor	239	62.07%
Job degree	General Manager	14	3.63%
	Project Manager	27	7.01%
	Implementation Manager	57	14.80%
	Technical Office Manager	97	25.19%
	Technical Office Engineer	107	27.79%
	Implementation Engineer	83	21.55%
Years of experience	From five years to ten years	183	47.53%
	From eleven to fifteen years	118	30.64%
	From sixteen to twenty years	51	13.24%
	More than twenty years	33	8.57%

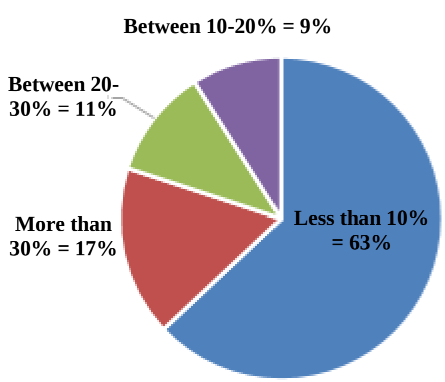

Fig. 4 Percentage of projects implemented using VE (37% Respondents)

According to the survey results, only 37% of respondents incorporated Value Engineering (VE) into their work. The frequency of application varied significantly among the patients who underwent VE. In particular, as shown in Figure 4.

- 63% of respondents applied VE to less than 10% of their projects.
- 17% applied VE to more than 30% of their projects.
- 11% applied VE to between 20-30% of their projects.
- 9% applied VE to between 10-20% of their projects.

These findings suggest that while a significant proportion of respondents recognize the value of VE, its adoption is still limited, and there is room for increased implementation across a wider range of projects.

According to the survey results, only 18 % of respondents incorporated sustainability into their work. The frequency of application varied significantly among those who applied sustainability, as shown in Figure 5.

- 82% of respondents applied sustainability to less than 10% of their projects.
- 2% applied sustainability to more than 30% of their projects.
- 7 % applied sustainability to between 20-30% of their projects.
- 9% applied sustainability to between 10-20% of their projects.

These findings suggest that while a significant proportion of respondents recognize the value of sustainability, its adoption is still limited, and there is room for increased implementation across a wider range of projects.

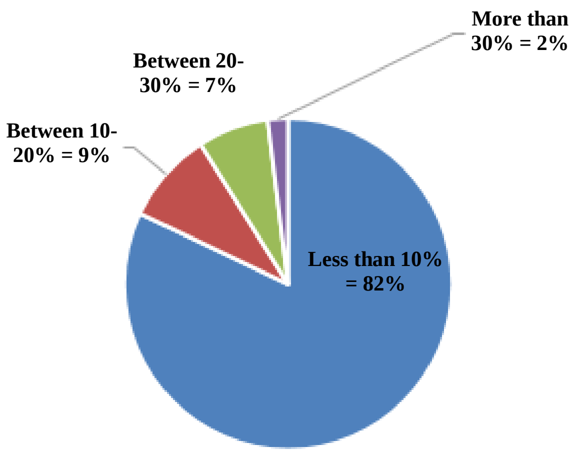

Fig. 5 Percentage of projects implemented using VE (18% Respondents)

4. Results and Discussion

Statistical analysis was conducted using SPSS version 20 to investigate the relationships among the 27 factors, employing validity and reliability measures. Traditionally, validity and reliability have been the staples of quantitative research; however, their application is now reassessed within the qualitative research paradigm. Given their origins in positivist thought, redefining them to accommodate their use through a naturalistic approach is necessary. Examining reliability and validity in quantitative research serves as a foundation for understanding their meaning in qualitative research. Similarly, triangulation, commonly used in quantitative research to assess reliability and validity, can provide valuable insights for optimizing the validity and reliability of qualitative studies [30]. Key statistical indicators, including the mean, standard error, and standard deviation, were computed for each factor to provide a comprehensive understanding of its characteristics, as presented in Table 4.

The following statistical measures were employed to analyse the factors:

- Cronbach's alpha: evaluate reliability by examining the shared variance, or covariance, through the elements in an instrument in relation to the total contrast.
- Mean: The mean is calculated by summing the data values and dividing them by the number of values, providing a measure of the central tendency.
- Standard Deviation (SD): A widely used indicator of variability, utilized both independently and as a component of other analyses.
- Standard Error (SE): The standard deviation of the sampling distribution of a statistic, representing the variability of sample means from the population mean due to chance sampling errors.

Table 3 presents the results, which indicate that the 27 factors exhibit internal consistency and are interrelated.

Table 3. Statistical analysis findings

CF Group	Code	Validity	Reliability	Cronbach's alpha	Mean	SD	SE
V.E. Factors to sustainable design	VESD.1	0.79	0.89	0.87	3.88	0.82	0.11
	VESD.2	0.78	0.88	0.86	4.10	1.03	0.14
	VESD.3	0.81	0.90	0.89	3.81	0.88	0.12
	VESD.4	0.80	0.89	0.88	2.61	0.84	0.12
	VESD.5	0.78	0.88	0.86	4.16	1.05	0.15
	VESD.6	0.81	0.90	0.89	3.11	0.68	0.09
	VESD.7	0.82	0.90	0.89	2.06	1.00	0.14
	VESD.8	0.79	0.89	0.87	1.61	1.02	0.14
	VESD.9	0.80	0.89	0.88	3.96	0.93	0.13
	VESD.10	0.83	0.91	0.90	2.78	0.89	0.12
	VESD.11	0.86	0.93	0.93	3.15	0.84	0.12
	VESD.12	0.85	0.92	0.92	2.31	0.88	0.12
V.E. Factors to sustainable construction	VESC.1	0.89	0.94	0.95	1.81	0.86	0.12
	VESC.2	0.88	0.93	0.94	1.08	0.60	0.08
	VESC.3	0.86	0.92	0.92	1.83	0.66	0.09
	VESC.4	0.88	0.94	0.94	3.56	1.13	0.16
	VESC.5	0.89	0.94	0.95	3.51	0.75	0.10
	VESC.6	0.86	0.93	0.93	3.73	0.76	0.10
	VESC.7	0.87	0.93	0.93	3.69	0.91	0.13
	VESC.8	0.90	0.95	0.96	3.13	1.00	0.14
	VESC.9	0.86	0.93	0.93	2.14	0.87	0.12
	VESC.10	0.85	0.92	0.92	2.84	0.79	0.11

	VESC.11	0.82	0.89	0.89	2.37	0.90	0.12
	VESC.12	0.91	0.93	0.95	1.11	0.99	0.14
	VESC.13	0.85	0.95	0.93	1.58	1.10	0.15
	VESC.14	0.81	0.90	0.89	3.61	0.97	0.13
	VESC.15	0.87	0.91	0.92	1.76	0.87	0.12

The primary objective of all stakeholders involved in a construction project is to effectively complete the project. This study aims to define, analyse, and evaluate Critical Success Factors (CSFs) that influence project performance.

Through a review of pertinent literature, articles, case studies, and research in the field, 27 factors were identified. Construction industry experts participated in a survey, rating the impact of each factor on project performance using a 5-point scale. The data gathered from these professionals were analysed using the Relative Importance Index (RII).

4.1. Relative Importance Index (RII)

A ranking analysis was performed to prioritize the factors influencing Egyptian construction projects according to their relative significance [31]. The findings are displayed in Table 3, while the corresponding Relative Importance Index (RII) levels are shown in Table 4. The RII was calculated using the following formula:

$$RII = (\Sigma (Wi \times Fi)) / (5 \times N) \quad (1)$$

Where:
RII = Relative Importance Index;
Wi = Weight assigned to each factor (1-5)
Fi = frequency of responses for each factor;
N = Total number of respondents

This analysis identified the key factors affecting Egyptian construction projects, offering valuable insights for industry stakeholders to create targeted mitigation strategies. The main goal of this research is to explore the root causes of factors that influence the optimization of sustainable building design and construction through value engineering in Egypt. Additionally, it aims to suggest strategies to alleviate or prevent these issues.

To accomplish this, the study identified and categorized the most significant causes, as detailed in Table 5. The results are derived from the insights of construction and building professionals in Egypt.

Table 4. RII (%) and level of importance for factors

CF Group	Code	RII	Rank	Level of importance
V.E. Factors to sustainable design	VESD.1	0.775	4	H
	VESD.2	0.820	2	H
	VESD.3	0.762	5	H
	VESD.4	0.521	16	M
	VESD.5	0.831	1	H
	VESD.6	0.621	13	H-M
	VESD.7	0.411	20	M
	VESD.8	0.321	24	M-L
	VESD.9	0.791	3	H
	VESD.10	0.556	15	M
	VESD.11	0.630	11	H-M
	VESD.12	0.462	18	M
V.E. Factors to sustainable construction	VESC.1	0.361	22	M-L
	VESC.2	0.215	27	L
	VESC.3	0.366	21	M-L
	VESC.4	0.711	9	H
	VESC.5	0.701	10	H
	VESC.6	0.746	6	H
	VESC.7	0.738	7	H
	VESC.8	0.625	12	H-M
	VESC.9	0.428	19	M
	VESC.10	0.568	14	M
	VESC.11	0.474	17	M
	VESC.12	0.221	26	L
	VESC.13	0.315	25	M-L
	VESC.14	0.722	8	H
	VESC.15	0.352	23	M-L

Table 5. Proposed mitigation recommendations for high-impact factors

CF Group	Code	Activity Name	Proposed Recommendations
V.E. Factors to sustainable design	VESD.1	Apply value engineering requirements during the early stage of sustainable design.	• Environmentally conscious design. • Applying concepts such as green building and environmental design. • Waste reduction and recycling. • Reducing greenhouse gas emissions. • Safely handling industrial waste. • Sustainability assessment and certification systems such as LEED and BREEAM.

	VESD.2	Providing alternatives and suggestions for sustainable design to achieve optimal project cost.	• Create a design that not only meets practical functionality but also dazzles aesthetically, all while keeping a watchful eye on expenses. Dive deep into thorough cost-benefit analyses to uncover hidden opportunities for cost savings and enhance resource allocation. • Implement a strategic value engineering approach to pinpoint and eliminate superfluous expenses, all while safeguarding the integrity and functionality of the project. • Harness the power of Building Information Modelling (BIM) alongside other cutting-edge digital tools to elevate design accuracy, slash errors, and streamline construction activities.
	VESD.3	Applying LEED and design requirements and their impact on cost and value engineering requirements.	• Dive deep into thorough cost-benefit analyses to unveil hidden avenues for cost savings, allowing for a more strategic allocation of resources that maximizes impact. • Embrace a value engineering approach to meticulously sift through project expenses, identifying areas where cuts can be made without sacrificing the integrity and quality of the work.
	VESD.5	Efficiency of the planning and design team, sustainability requirements and value engineering.	• Sniff out and eliminate any unnecessary costs without sacrificing the quality and functionality of the project. • Join forces with stakeholders throughout the design development journey, and their insights are invaluable in ensuring that our design aligns with their expectations and needs, helping us dodge any costly changes or claims down the line.
	VESD.9	Cost analysis during the project planning stage.	• Establish the project scope, assess costs and benefits, assign monetary values, calculate the net present value (NPV), analyze the results, and make informed decisions. • Comparing the total anticipated costs with the expected benefits to evaluate the project's overall value.
V.E. Factors to sustainable construction	VESC.4	Reduce the construction materials emissions.	• Constructing with low-carbon materials can greatly decrease a building's embodied carbon emissions. • Utilizing low-carbon concrete or exploring alternative structural systems like mass timber or hollow core panels.
	VESC.5	Renewable and clean energy sources are used.	• Lowe greenhouse gas emissions: Utilizing renewable energy sources decreases carbon dioxide and other harmful gas emissions. Strengthening energy security. • Promote sustainable development: Helping to deliver affordable and sustainable energy to communities.
	VESC.6	Monitoring water consumption performance.	• Reducing potable water consumption. • Apply efficient equipment for water use.
	VESC.7	Prepare a plan for waste management of construction and demolition.	• Preserve the raw materials used and reused. • Apply the five principles of waste management: reduce, reuse, recycle, recover, and manage waste.
	VESC.14	Continual communication between management and workers and correcting unsafe practices.	• Preparing an emergency response plan. • Implementing an occupational safety plan. • Holding periodic meetings with employees.

5. Conclusion

This research paper identified the factors that hinder the implementation of the optimization of design and construction for sustainable buildings using value engineering in Egypt. Key barriers identified include gaps in knowledge, stakeholder issues, challenges with standardization, and environmental and cultural factors, as well as dynamics within workshops. Specific obstacles, such as the lack of involvement from decision-makers, the absence of regional guidelines, reluctance to embrace value management and time constraints, have been recognized as significant challenges. The study also highlighted ongoing issues, including an insufficient understanding of value management principles and a lack of regional standards. These findings underscore the need for a comprehensive approach to addressing these barriers. It was concluded that overcoming these challenges is essential for successfully implementing value management. To facilitate this, organizing workshops to encourage the adoption of value management in the industry was recommended. These insights can help shape strategies aimed at improving the efficiency of sustainable resources.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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