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Sustainability-Based Value Engineering Management as an Integrated Approach to Construction Projects

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Abstract: The integration of sustainability standards and value engineering methods in public education projects is a significant concern, as it ensures the well-being and sustainability goals of students, lecturers, and employees. This study aims to enhance sustainability within public education campuses by utilizing value engineering processes that establish a balanced correlation between the available budget costs and the sustainability costs that affect educational objectives, strategies, and the overall sustainability of the environment. In order to evaluate the integration of value engineering and the sustainability rating system "LEED protocols" for schools, the study utilized HAP (Hourly Analysis Program) software to perform numerical analysis, with the objective of improving environmental efficiency and cost-effectiveness in school buildings from the perspective of both male and female students. By applying this approach to all engineering disciplines, systems, and materials involved in the project, the study achieved impressive results, including a reduction in energy usage by 53.67%, a cost reduction of 27.48% from the total project budget, and 13 points earned in credit C1 and credit C2 in the Energy and Atmosphere EA category in LEED 2009. These findings are of great importance for the planning and execution of construction projects, specifically in the context of educational infrastructure, and provide valuable insights into the construction and renovation of school buildings, which can be used to enhance the safety, functionality, and aesthetic appeal of these facilities.

Keywords: value engineering stages; sustainability rating system; construction project management

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1. Introduction

Environmental issues have become multidimensional and interconnected. Therefore, systematic and integrated processes are needed to support organizations' decision-making to succeed in their investments and management [1]. The integrated and routine procedures in the environmental management approach reduce the consumption of resources and operations' negative impacts in addition to promoting sustainability [2]. The sustainability of university campuses has become a concern for educational organizations as they seek to organize and adjust their environmental approaches regarding the effects of the universities' activities and operations on the environment. The ministries of education in some countries, such as Saudi Arabia, encourage universities to participate in a sustainability rating system to rank their commitments in sustainability aspects as well as to achieve a high-level green campus [2,3].

A green campus-built area supports students' lives inside the campus, enhances their environmental protection awareness, and guides them toward the direction conducive to sustainable development behavior in daily life [4]. Sustainability performance across various stages of the construction project's lifecycle is affected by different factors [5]. The goals of sustainable construction methods and building service systems, including using renewable and recyclable resources, are to support the reduction in the industry's impact on the environment, reduce energy consumption and waste, create a healthy and friendly environment, protect the natural environment, decrease carbon dioxide emissions, and preserve natural resources [6–8].

Lifecycle value evaluation is a practical process involving the adoption of substitutes and alternatives in the construction industry while considering the available project budget and enhancing building systems and materials, which are of high concern for all construction organizations [9]. Scrutinizing energy performance throughout the project building's lifecycle, starting from the design stage, in all public buildings with an educational purpose, such as school buildings, supports their social responsibility to move toward sustainability standards while giving due consideration to all possible alternatives for achieving optimum cost savings and avoiding overrun costs [10,11]. The energy consumption in Saudi Arabia's governmental buildings has reached about 13% of the total energy consumption of the country, and construction projects consume up to 70% of the power through the building of structures and air conditioning [12]. The current economic conditions necessitate that all organizations use feasible methods and applications of systems as well as materials techniques to help improve sustainable performance involving various construction participants and stages [13,14]. Incorporating sustainability into construction projects facilitates utility operation and maintenance cost savings [15].

Value engineering (VE) is an execution study by a multidisciplinary professional team using analytical systems applied to a particular project, product, or service to improve the functions at a lower cost. It focuses on process performance by recommending the adoption of alternative methods and materials with the required quality [16]. The integration of sustainability and value engineering (VE) creates the potential to enhance the value of a construction project [17]. Value engineering management (VEM) has several goals in construction projects; one of its goals is to provide an approach to sustainable construction projects based on local and international sustainability standards to enhance the building's systems and materials, achieve green construction, adopt environmentally friendly resources, and influence project costs and quality [18,19].

Value is the connection ratio between the required performance function and overall costs, which is affected by either process improvement or cost reduction. Value engineering (VE) is a technical and systematic procedure to reduce costs, maintain project value, and provide benefits from schedule-related savings and quality improvements [20–22].

Quality and value are critical factors in construction projects. In contrast to cost reductions through the use of less expensive alternatives to specified materials or systems, higher quality as value added for the client creates a balance between the initial and running construction costs. It reduces maintenance costs over the project lifespan [22,23]. A VE job plan is associated with eight crucial phases, including considerations like analysis and preparation for the project, gathering information and investigation, creation of ideas and function analysis, creative brainstorming for alternatives, speculating and identifying alternatives, evaluation of lifecycle cost alternatives, development of other options, presentation of implementation recommendations, and close-out for the implementation analysis and evaluation of outcomes [24,25].

A sustainable construction project aims to reduce the adverse health and environmental impacts caused by the construction process or built-up environment [25,26]. Sustainable development interconnects the environment, society, and economy with a systematic approach to achieving a range of goals in health and environmental aspects [27,28]. Sustainable construction contributes to ecological factors, i.e., reducing global greenhouse gas emissions. Furthermore, it encompasses designing and managing built structures and identifying the performance of materials and systems technologies through project lifecycles, building operations, and maintenance. Sustainable construction contributes to economic aspects by promoting a circular economy by using waste and materials recycling, renewable energy generation, water preservation, feasibility analysis of technologies, and finance modeling. Sustainable construction also contributes to social aspects, i.e., adherence to the highest ethical standards in all project construction industry phases, promoting socially viable living and working environments, applying safety standards, and using the built environment as a commonwealth [29,30]. Sustainable construction is responsible for healthy built environment management in accordance with efficient and ecological principles and resources [31]. The sustainable construction criteria have efficient strategies and objectives in initial cost, cost in use, and recovery cost for human health and comfort [32,33]. Figure 1 illustrates the interactive management target between sustainable objectives and strategies and the applicable sequence of value engineering in construction projects, representing the integration management field in analyses with strategies, scope, and objectives, which can be applied to construction projects' sustainability value engineering management (SVM). LEED (Leadership in Energy and Environmental Design) aims to achieve six main principles set for sustainable construction [34,35], including conserving resource consumption, protecting the natural environment, creating a healthy and non-toxic environment through resource reuse, and using renewable, recyclable resources in the environment built.

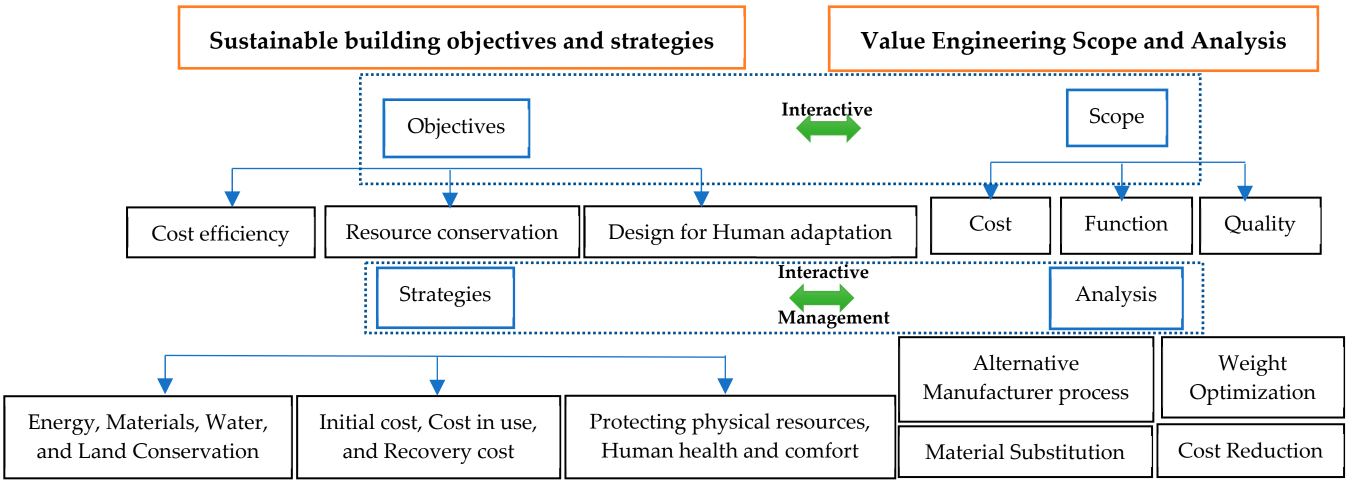

Figure 1. The sustainability and value engineering interactive management in construction projects.

LEED is a rating system focused on several building project types based on a points system, and the higher rating system for the design and construction of entire buildings focuses on accessibility [36]. This rating system is for new installations or significant renovations [37]. The LEED for Schools 2009 checklist from the LEED V4 rating system used for school campuses and buildings comprises a checklist encompassing eight categories: sustainable sites, water efficiency, energy and atmosphere, material and resources, indoor environmental quality, innovation, design process, and regional priority [34,35,37,38]. Appendix A Figure A1 depicts the process of integrating the sustainable standard LEED for Schools 2009 checklist from the LEED V4 rating system standard with numerical accounting points from LEED V4. The energy and atmosphere (EA) category has a targeted weightage of 33 points, with 16 points attempted in the design stage and 17 points attempted in the execution stage. During the evaluation stage of value engineering, the study can determine how many points the case study can achieve.

The construction industry deals with projects that proceed through a lifecycle. From a lifecycle perspective, all materials and systems should be evaluated for their value in supporting the lifecycle goals of a building or facility [39–41]. The lifecycle concept expanded upon considering the lifecycle as a continuous process and proposing a reference to cradle-to-cradle (C2C) instead of cradle-to-grave (C2G) [41,42]. The construction project lifecycle entails five critical stages as a process group: initiating, planning, executing, monitoring and controlling, and closing. Initiating refers to processes that support establishing the project start, including the project initiation document (PID), which considers the design document for bidding, determining the primary project goals, identifying project team members, modifying project plans, and solidifying the project budget. Group monitoring and controlling involve effort and cost tracking to determine whether the budget is on track [43].

Project sustainability involves individual and organizational responsibility to ensure that the outputs, outcomes, and benefits are sustainable over lifecycles and during their creation, disposal, and decommissioning. Building sustainability into the project vision has become a high concern for organizations [44]. The presentation and communication of the sustainability value could be considered vital for embedding sustainability early in the project lifecycle. It is essential to embed sustainability in the early budget planning and funding approval process to build the sustainability measures and documents adopted in the project lifecycle as well as to avoid the risk of becoming unsustainable from an economic perspective. The organizations utilize the lifecycle sustainability assessment (LCSA) to evaluate and update all environmental, social, and economic impacts and benefits in the decision-making processes toward more sustainability throughout their construction project lifecycle [45].

Value engineering and lifecycle costing are two essential tools for cost management control in design-build (DB) projects and optimizing the performance, quality, and sustainability of projects while minimizing the total cost of ownership [46]. Although value engineering commenced as a cost-saving measure, it is becoming a valued project management technique that addresses all aspects of the building lifecycle from the initial construction through the sustainability of sourced materials to the utility efficiency of the final project and constantly measuring budget variance [47].

The following sections of this paper take account of exploring the study methods and materials, the results of the proposed value/sustainability management approach, the results discussion, the study's conclusion, and limitations and opportunities for future research. Figure 2 illustrates the study method flowchart, elucidating the skeleton of the objective, the software for analysis, the systems used, and the case study results.

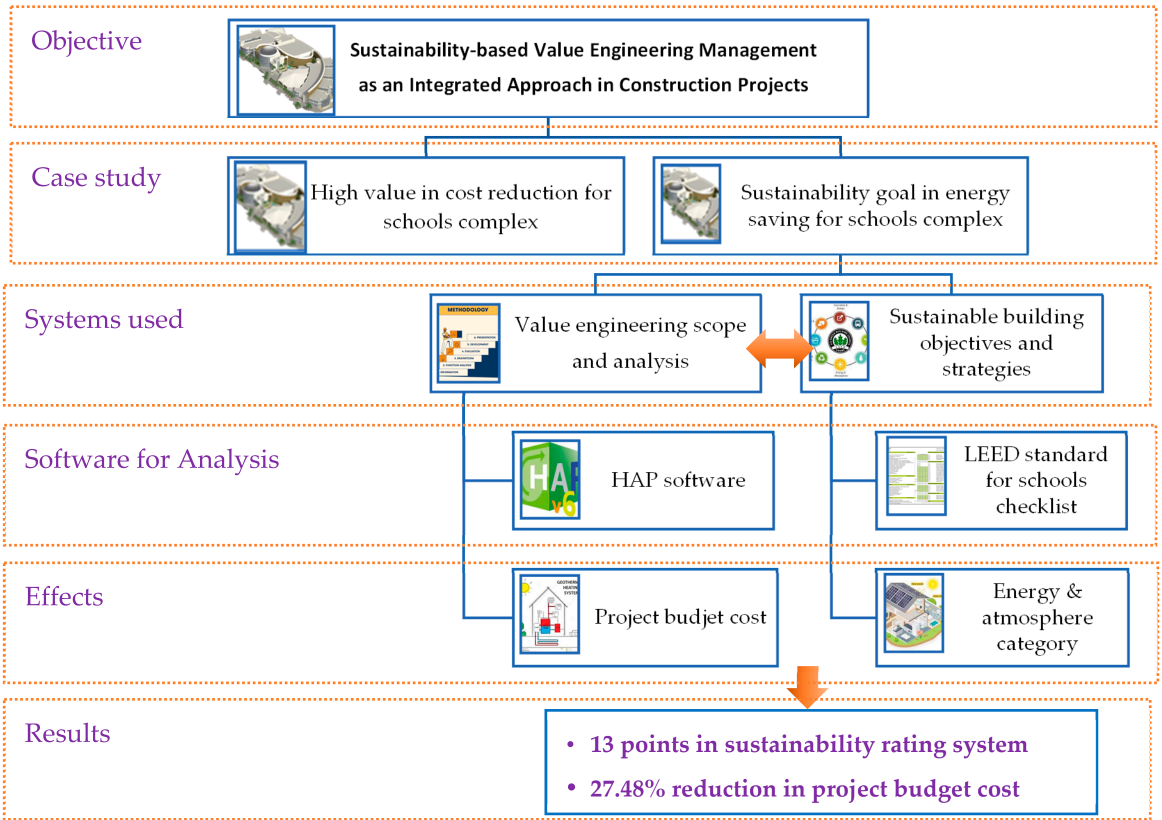

Figure 2. Study method flowchart management.

The following are the essential research questions: What would be the advantage of including sustainability items during the evaluation stage of value engineering? Which practical items related to energy-saving criteria can assist decision-makers in achieving high credits in the sustainability rating system for a public university project situated in a desert? How would the integration of value engineering stages into a sustainability rating system impact the reduction in project costs? The research questions aim to shed light on the significance of sustainability in value engineering and its impact on project cost reduction. Specifically, the questions seek to explore the benefits of merging sustainability factors during the evaluation stage of value engineering. They also aim to identify which energy-saving criteria can assist decision-makers in a public desert university project in achieving a high sustainability rating. Finally, the questions aim to investigate how value engineering stages with a sustainability rating system can affect project cost reduction.

This study aims to evaluate how the analysis scope of value engineering and the sustainable rating system LEED for Schools 2009 checklist from the LEED V4 rating system can be incorporated and integrated. The key objective is to reduce costs and improve the building's efficiency based on numerical analysis using HAP software. The study focuses on the evaluation stage of value engineering using an applied sustainability rating system. Through partnerships between various agencies, including the university's team, local value engineering organizations, national education services, private manufacturer firms, and municipal governments, the study achieved energy and cost reductions that meet sustainable standards.

2. Literature Review

The paper by [1] contributed to the discourse on sustainable development (SD) by further explaining the paradigm and its implications for human thinking and actions in the quest for sustainable development. It found out that the issue of sustainable development is completely anchored on three-dimensional distinct but interconnected pillars, namely the environment, economy, and society. The paper by [2] discussed energy systems in school classrooms that underlie all human economic activity and the prospects for their transformation in a short time, in addition to updating energy trends broadly. The paper by [3] illustrated the environmental pollution and degradation caused by universities in the form of energy and material consumption via activities and operations in teaching and research and proposed a framework for achieving campus sustainability that could deal with the limitations of the current environmental management practices in universities and ensure more sustainability. The paper by [4] focused on the energy-saving impact of the sustainable development of a green campus and provided a referenced experience and new development proposals for global campus sustainability. The paper by [5] investigated the factors affecting sustainability performances during the construction stage of building projects in the Gaza Strip from consultants' viewpoints and pointed out that one of the most influential factors is economic and energy costs. The paper by [6] discussed various environmental problems rising in the construction industry, leading to the consumption of more energy, resources, and raw materials, which are responsible for the rise in carbon content in the air, which is harmful to the environment and human health. The paper by [9] argued that the design of green buildings should begin with the selection and use of eco-friendly materials with better features than traditional building materials. Building materials are usually selected through functional, technical, and financial requirements. Energy efficiency is weighted heavily in most green building programs. The paper by [11] illustrated that the overall purpose of this research is to achieve a functional benchmarking based on the real operation conditions of school buildings by the exploitation of the results made public through an intensive literature survey on energy consumption in schools. The paper by [15] suggested the passive refurbishment of public schools with some affordable interventions regarding the climate features and the reduced capacity to support the operating costs through the prototype construction, including an improvement in the envelope and technical systems. The paper by [19] showed that the sustainability approach deals with all the surrounding resources, such as water, energy, and material lifecycles, from their beginning as raw materials until their salvage cycle. It presented a case study of value engineering applications in the sustainability disciplines in a real large-scale residential project. The study by [24] aimed to create a framework that combines virtual environment (VE) and sustainability concepts in Sri Lanka's construction industry to enhance project values. The research used both quantitative and qualitative methods. The questionnaire survey, conducted as a part of the research, received a response rate of 68.9%, and the collected data were analyzed using the relative importance index (RII). After the survey, 15 interviews were conducted with experts, and the findings were analyzed using content analysis.

The study by [25] highlighted the importance of using value engineering as a useful tool from the beginning stages of studying and designing to the end stages of constructing, maintaining, and exploiting processes. The study briefly introduced the concepts and executive process of value engineering in construction projects and compared them with conventional methods of evaluating project function. The research findings indicated that value engineering can help achieve a project's objectives while minimizing costs, as it is a crucial factor in the construction project management sector, especially in third-world countries.

The paper by [26] presented the research design of a research-in-progress aimed at understanding different firm's approaches to mainstreaming sustainable construction. The paper by [30] investigated the relationship between the principles of sustainable development and the construction sector. Drawing on information from 14 countries, the study identified the main issues, constraints, and current policies and predicted changes and adaptations for the construction sectors in each country. The paper by [33] discovered that various assessment tools are being developed globally to establish an efficient framework for measuring the environmental performance of the construction process. One such tool is the Leadership in Energy and Environmental Design (LEED) certification, which has a certification program for new buildings and major renovations called LEED BD+C. This tool can be used to promote sustainability by considering the role of construction in the process. The study by [37] reviewed the rating systems to emphasize the importance of energy efficiency parameters in education buildings. The methodology is performance-based, utilizing an energy-plus application. The experiments investigated the variables (orientation, window-to-wall ratio, U-value, SHGC, shading, and occupancy) affecting the energy consumption of classrooms. The study by [39] illustrated that the construction of new school facilities or retrofits of older facilities is a significant infrastructure investment for many municipalities over the next several decades. Moreover, studying the impact of sustainable design on the health and performance of occupants also needs to include environmental science and social science perspectives to inform the best practices and quantification of benefits beyond the general measures of cost savings from energy efficiencies.

Sustainability and value engineering are important considerations in the construction industry. However, most previous research studies have focused on assessing sustainability during the project initiation stage or throughout the construction and building operation/maintenance stages. There is a lack of research studies that addressed sustainability and value engineering in the execution processes phase. Furthermore, there are few guidelines available that integrate value engineering as part of the lifecycle's costing with sustainable development in the design phase. The purpose of this study is to provide a practical and scientifically incorporated guideline matrix for a construction project. This guideline matrix is based on integrating sustainability criteria standards with the value engineering stages and is presented as a prototype through a case study. The study provides a practical guide for decision-makers, stakeholders, and enterprises working in the construction projects field to achieve the sustainability criteria while saving costs. The study also facilitates the design of a new approach for teaching a curriculum in integrating value engineering stages with sustainability standards. It opens gates for software designers to upgrade programs, i.e., ArchiCAD, Revit, and ArcGIS, to support the students and practitioners in making robust and precise studies and applications.

The study results evidenced the benefits of merging sustainability criteria based on the points as numerical parameters in the evaluation stage of value engineering. The study focused on energy-saving criteria as an example to support the organization's decision-makers, education universities, and the construction industry to achieve a high ranking in the sustainability rating system with cost reductions. The study provided a comprehensive approach to the integration of sustainability and value engineering. It enabled practitioners to organize environmental, economic, and social data in a structured form based on all material and system lifecycles. This approach facilitates clarifying the trade-offs between the three sustainability pillars and the impacts of lifecycle stages and value engineering stages. It also promotes awareness in value chain actors on sustainability issues, enables further improvements in the case study of lifecycles, i.e., energy improvement and saving, and supports decision-makers in resource prioritizing based on the positive and negative impacts of sustainable technologies, cost-efficiency, and eco-efficiency to raise case study credibility.

3. Materials and Methods

3.1. The Case Study

The selected case study was conducted in Al-Ahsaa City, an eastern province of the Kingdom of Saudi Arabia. The case study is the School Complex for Boys and Girls (SCBG), an ambitious investment project at King Faisal University. The author of this study is working as a consultant coordinator for the complete King Faisal University KFU campus projects and is a certified engineer in value engineering (VMA), is certified in the sustainability rating system (LEED GA) and is the team leader who undertook this study by applying all data from the actual project of the KFU campus field. It had been designed at two sites and developed inside a housing area to serve the families of students of university employees and staff according to the admission and registration priorities by the assigned committee [48]. The SCBG is located inside the housing area center of King Faisal University [49]—each school has a total area of 20,000 m^2, 1560 students, 57 classrooms, eight labs, and 384 teachers. According to the whole project's tender budget, the percentage of work for architectural, civil, electrical, and mechanical disciplines is 36.82%, 14.16%, 25.02%, and 24%, respectively. The total demand for energy for the total tender SCBG project area is 15,761.30 kW [49,50].

In the upstream construction sectors, most of the existing studies and literature have not used sustainability standards in value engineering and lifecycle-costing concepts [51]. Identifying the cooperation method between sustainability standards and the value engineering approach is a critical issue and forms a challenge due to its specific effect on the environmental and economic aspects. The calculation of the total points that a project can earn by installing the required credits in the energy and atmosphere (EA) category of the LEED for Schools 2009 checklist, which is part of the LEED V4 rating system, is mentioned in Appendix A Figure A1, which needs comprehensive knowledge and vast experience in the construction industry [52]. Thus, this study attempts to fill the gap in the existing knowledge by using numerical analysis to incorporate the sustainable standard criteria into value engineering stages to build an approach to enhancing the lifecycle through the case study. The numerical analysis involves quantifying sustainability points from the energy and atmosphere (EA) category of the LEED for Schools 2009 checklist and calculating the cost savings from accepted ideas (a material or system alternative item) and energy savings by analyzing the output generated by renewable energy, using HAP software for the energy analyses across mechanical, electrical, and architectural disciplines' materials and systems. The study involving the experts' evaluation team used value engineering stages to construct the methodology based on two essential stages. The first stage is the creative stage, which proposes alternative ideas for all disciplines to be evaluated with a specific range from 0 to 10. This stage enhances the project's lifecycle, can achieve cost reductions with a high sustainability ranking, and develops the architectural design that keeps the essential school function elements. There are four levels of certification in the LEED rating system that a project can obtain through the sustainability ranking: Certified (40–49 points), silver (50–59 points), gold (60–79 points), and platinum (80+ points), out of the total points achieved through the eight categories of the LEED for Schools 2009 checklist, which is part of the LEED V4 rating system. The second stage is the evaluation of the best lifecycle and lowest-cost alternative ideas. The points can be obtained as per the LEED for Schools 2009 checklist to achieve a certain level of sustainability ranking and energy savings, such as in the following case study as an example, where the review process for the two stages involved analyzing the study's space program, all design systems, and material load calculations for the proposed alternative ideas mentioned in the contractual document. This document contained mechanical and electrical items. All alternative ideas that met the approved weight category were selected based on the LEED for Schools 2009 checklist from the LEED V4 rating system standard, which promotes sustainability. The standard is described in Appendix A, Figure A1. It illustrates that each credit in each category has a value (points) that is dependent on the installation of technical procedures. The study used the lifecycle sustainability assessment (LCSA) for all environmental, social, and economic negative impacts and benefits using a goal and scope definition, inventory analysis, impact assessment, and interpretation for each material and system.

3.2. The Study Methodology

The study methodology's two stages can be explained as follows:

3.2.1. Creative Stage

This study contemplates that electromechanical systems and materials adversely affect costs, health, and the environment [53]. The LEED for Schools 2009 checklist is a part of the LEED V4 rating system, which has eight categories of focus: Location and transportation (15 points), sustainable sites (12 points), water efficiency (12 points), energy and atmosphere (33 points), materials and resources (13 points), indoor environmental quality (16 points), innovation in the design process (6 points), and regional priority (4 points). Projects earn credits in these areas to achieve certification. Each category contains a certain number of credits. Each credit has a number of specific requirements that must be fulfilled, and upon meeting the requirements, the project will earn points (Appendix A Figure A1). The higher the total points a project earns, the higher the level of LEED certification it will be awarded. The LEED for Schools 2009 checklist from the LEED V4 rating system content points required in the energy and atmosphere (EA) category, as evaluation parameters for sustainability, take into account some of the prerequisites and credits. The prerequisites include the Fundamental Commissioning of the Building Energy Systems, Minimum Energy Performance, and Fundamentals. The six credits include Optimize Energy Performance, On-Site Renewable Energy, Enhanced Commissioning, Refrigerant Management, Measurement and Verification, and Green Power. These parameters are applicable and comparable sequence approaches with value engineering [54,55]. By speculating about using creative techniques to identify alternatives that can provide the required functions, the team achieved this in three steps. The first step was to search for options for the site allocation of the boy's school complex to complete more prerequisites in accordance with certain factors like the nearby access gates, walking distance from home to school, traffic level, and infrastructure nearby, etc. The second step was to develop a modified architectural design that keeps the essential school function elements and supports the integration between the LEED sustainability requirements in architectural and electromechanical materials and systems, as well as achieving specific values in the number of spaces according to international standards. In the third step, according to the previous architectural modifications, the team proposed many alternative ideas in all disciplines for evaluation, with a specific range from 0 to 10. The evaluation stage included members from the mechanical, electrical, civil, and architectural disciplines. To evaluate each proposed idea for changing or modifying materials and systems in each discipline, weight was assigned as a quantitative parameter. These parameters are prepared based on several factors, such as the cost of implementation, flexibility of implementation, and possible implementation. The team calculated the average for each idea result and accepted the idea (a material or system alternative item) having the points within the acceptance range from 7 to 10. Table 1 illustrates the statistics of the proposed ideas based on the expert discussion results. Several proposed ideas include 58 ideas in development design, 23 ideas in architecture, 6 ideas in civil, 11 ideas in mechanical, and 9 ideas in electrical, while the accepted ideas include 38 ideas in development design, 21 ideas in architecture, 6 ideas in civil, 8 ideas in mechanical, and 9 ideas in electrical.

Table 1. Statistics of the study's proposed ideas.

The Discipline	Discipline Items Cost	Proposed Ideas	Accepted Ideas
	%	(No.)	(No.)
Development of the Design Ideas	-	58	38
Construction Architectural Ideas	36.82%	23	21
Construction Civil Ideas	14.16%	6	6
Construction Mechanical Ideas	25.02%	11	8
Construction Electrical Ideas	24.00%	9	9

The study analyzed the cost-effectiveness of the accepted ideas as alternatives in the four disciplines and the total points attempted in the execution stage in the energy and atmosphere (EA) category of the LEED for Schools 2009 checklist from the LEED V4 rating system. The LEED rating system comprises eight categories, which are described in Appendix A Figure A1. This stage is conducted before the cost impact study. In this stage, the reduction in areas after the modifications was estimated and compared with the basic design based on the cost per square meter of the building surface. During brainstorming meetings, proposals and ideas were reviewed by experts in both value engineering and sustainability. These ideas were refined in the evaluation stage by removing administrative and financial restrictions. The experts evaluated the ideas based on certain criteria: Whether the idea had been tried before, the cost of implementing the idea, the possibility of implementing the idea, compliance with codes and laws, and the flexibility of implementation. Each expert judged each idea on a score from zero to ten. The coordinator then calculated the average score for each idea in each discipline. The committee selected the ideas that scored seven out of ten or higher (the accepted average is seven and above) to move to the evaluation stage.

Appendix A Table A1 illustrates the total proposed ideas in the value engineering process development step. Figure 3 shows locations of applying the proposed concepts in the SCBG project on the ground floor for architectural, mechanical, and electrical disciplines, directly affecting energy savings. Figure 4 shows the locations of applying the compatible ideas in the SCBG project on the first floor for the architectural, mechanical, and electrical disciplines, directly affecting energy savings. Figure 5 shows the locations of applying the compatible ideas in the SCBG project in the tender and study perspectives. Appendix B Table A2 presents the quantities of eight architectural items that had been changed from tender items to value engineering/sustainable items after applying this study. Appendix B Table A3 presents the quantities of 16 civil items that had been changed from tender items to value engineering/sustainable items after applying this study. Appendix B Table A4 presents the quantities of 13 electrical items that had been changed from tender items to value engineering/sustainable items after applying this study. Appendix B Table A5 presents the quantities of 17 mechanical items that had been changed from tender items to value engineering/sustainable items after applying this study.

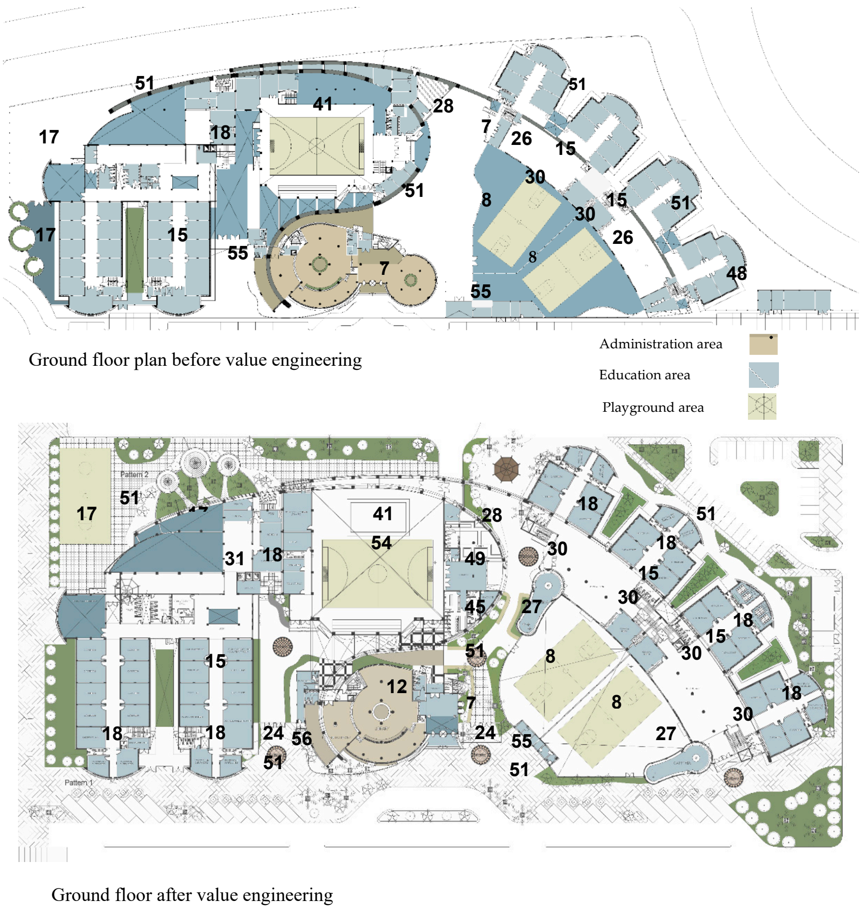

Figure 3. Applying value engineering ideas on the ground floor of the case study project.

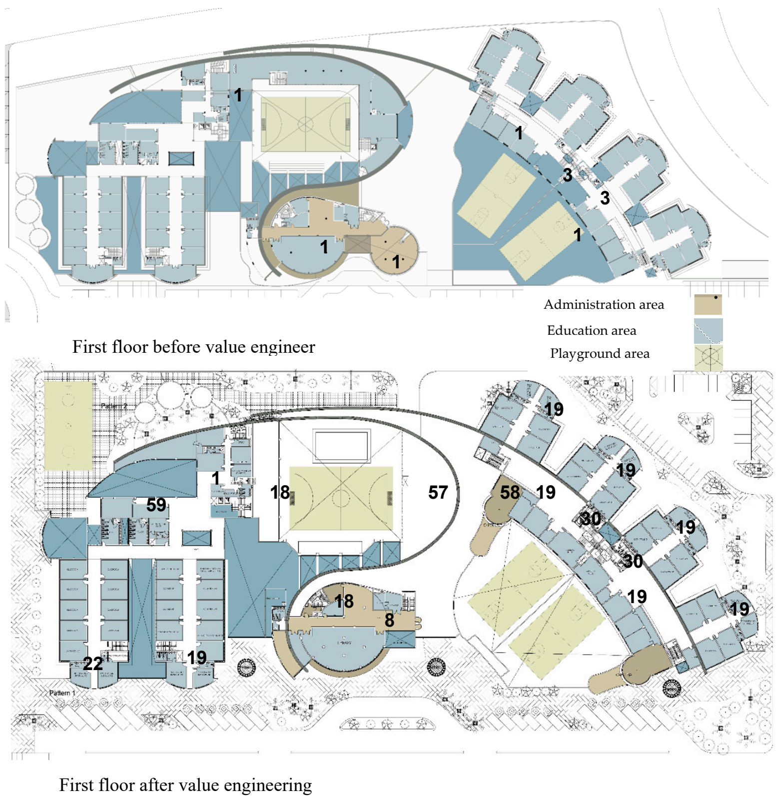

Figure 4. Applying value engineering ideas on the first floor of the case study project.

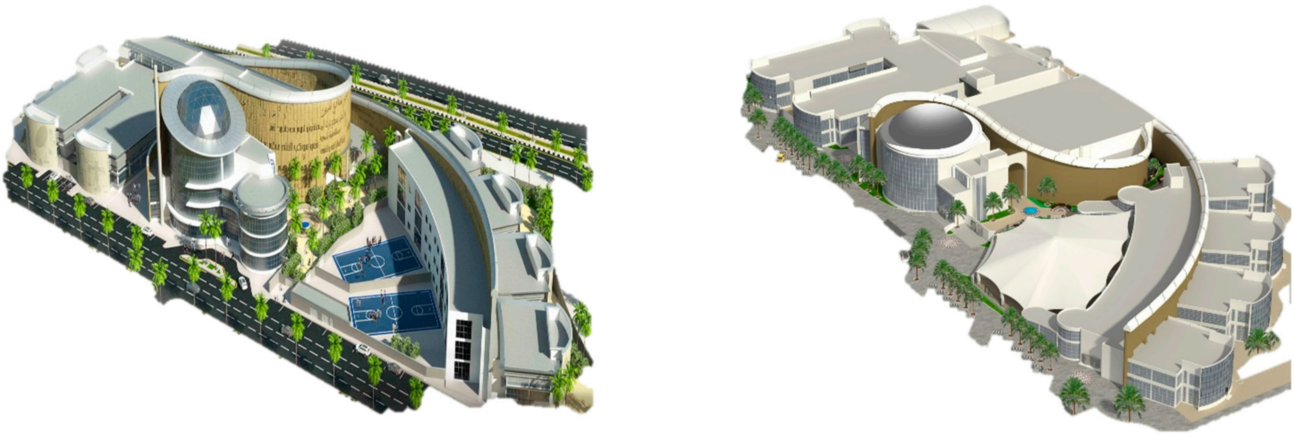

Figure 5. Applying value engineering ideas on perspectives of the case study project.

3.2.2. Evaluation Stage

The evaluation stage is the main stage in the value engineering stages and identifies the 3 best lifecycle cost alternatives for each system and material and the best alternatives for achieving high quality in a sustainable rating system. The team achieved this stage in two steps. The first step was to review the space program to study the possibility of increasing the school capacity to more than 1368 students and all related activities according to international standards to reach a new perception of the spaces compatible with the local standards and environment culture. The second step was to develop all the design calculation loads for the systems and materials in the contractual items involved in the mechanical and electrical disciplines in accordance with the approved ideas and architectural modification in the previous creation stage.

The total tender design demand energy loads became 15,761.3 kW: 12,544 kW for air conditions, 716 kW for plumbing works, 1693.50 kW for power, 117.00 kW for elevators, and 690.80 kW for both standard and emergency lighting. Table 2 illustrates the tender electrical loads for the electromechanical systems distributed through 12 MDP (main distribution panel) [43].

Table 2. Tender energy loads for electromechanical systems (12 MDP).

Systems/Loads	Plumbing Work	Elevators	AC System	Power	Lighting	Total
Electrical loads/KW	716	117	12,544	1693.5	690.8	15,761.3

All study result calculations were made based on the evaluation stage from the value engineering study, which included the complete load calculation for the mechanical systems according to the approved equipment and devices from suppliers/manufacturers, the total load calculation for the electrical systems according to the approved equipment and devices from suppliers/manufacturers, and the full architectural parameters, i.e., UV for all external glass composites. According to the previous information, the consultant experts used HAP software as a computer tool for estimating the loads, designing systems, simulating building energy use, calculating energy costs, and analyzing the air-system sizing for all spaces to technically compare the before and after energy consumption savings. This software was used to prove the achieved results in sustainability value and saving costs based on the study guideline in energy and atmosphere (EA) sustainability credit, which is used in the evaluation stage of the value engineering stages. One sample of air-system sizing is illustrated in Appendix A Figure A2. The third best lifecycle cost alternative is installing PV panels and BIPV over rooftops for playground shade, sports buildings, and domes as renewable energy sources to reduce the total energy consumption and construction costs, as well as to facilitate the maintenance and operation of the school complex. The total calculated and allowed area, with an excellent potential to produce clean energy, is 5730 m^2, which can be covered with 3000 solar modules to generate 1311 kWp and 3,828,120 kW/year [42,43]. Figure 6 illustrates applying solar rooftop locations in the SCBG project with 1050 m^2 for domes, 3630 m^2 for the playground, and 1242 m^2 for the sports hall. The fourth financial study was conducted to ensure that all previous items mentioned in the creative and evaluation stages had no contractual conflicts or problems with the budget or the competitor's ranking.

Dome **Sport hall** **Playground**

Figure 6. Applying solar rooftops in the dome, sports hall, and playground.

4. Results and Discussion

According to the site allocation of the boy's school complex alternatives, the chosen location, according to certain factors, affects the infrastructure's network length, especially in medium voltage cables that affect the total cost and energy consumption.

The developing of a modified architectural design and reviewing the space program provide high potential to alter the space quantity and reduce the total building area to 54,000 m^2 instead of 74,000 m^2, modifying the building height from three floors to two floors, and adapting the SVM support to increase the school capacity to reach 1586 students rather than 1368 students in the tender design capacity, taking into consideration the international standards. All these results reduce the total energy demand in SCBG, which appears obviously in the modified load energy calculations in both electrical and mechanical systems. The total demand energy loads after the SVM study became 6269.05 kW for air conditions, 66.07 kW for plumbing works, 505.50 kW for power, 101.6 kW for elevators, and 205.89 kW for both standard and emergency lighting. Table 3 illustrates the electrical power modification for the electromechanical systems through 6 MDP after the SVM study, and Figure 7 illustrates the energy comparison as the tender and SVM in the case study.

Table 3. Energy power modification for electromechanical systems (6 MDP) after SVM study.

Systems/Loads	Plumbing	Elevators	AC System	Power	Lighting	Total
Electrical loads/KW	66.07	101.6	6269.05	505.5	205.89	7148.11

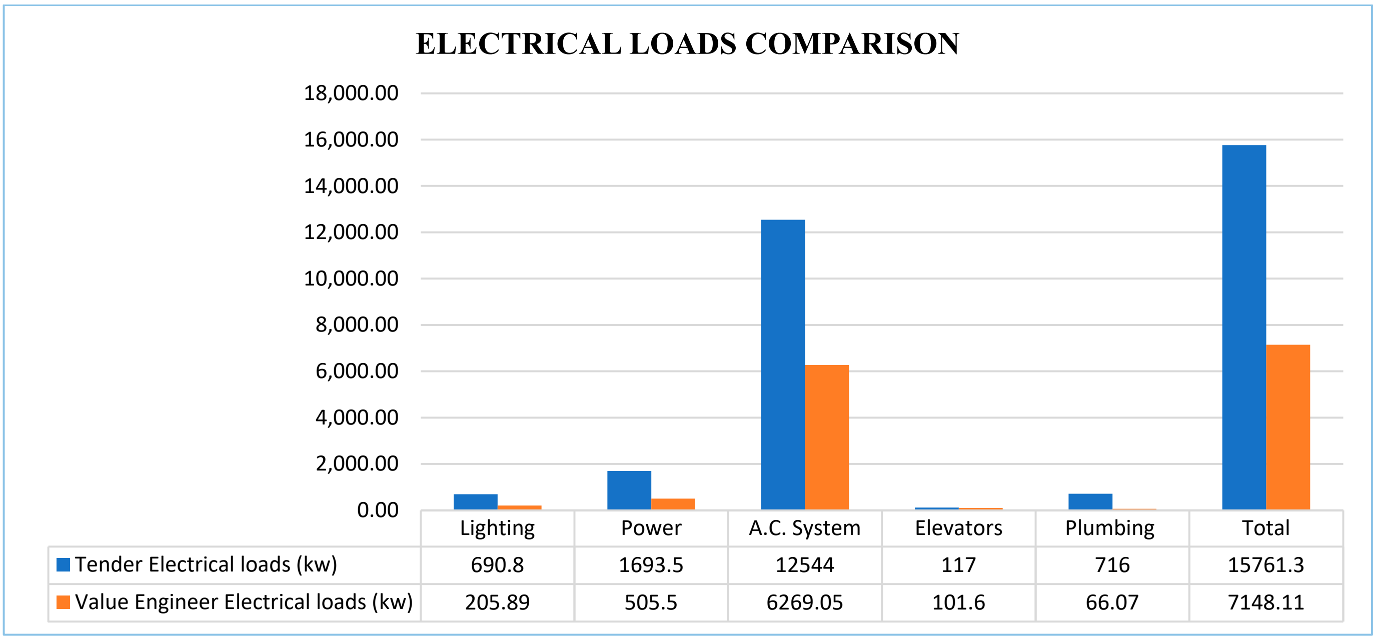

Figure 7. Energy comparison of tender and SVM in the case study.

Applying solar rooftops in a total area of 5730 m^2 over the dome, playground, and sports hall generates 190 kWp, 835 kWp, and 286 kWp, respectively, with a total of 1311 kWp (8 h) and 3828.120 kW/year. It results in an energy reduction percentage of 8.32%, which means energy savings of 1311 kW/day, with the cost savings reaching about 3461.04 (8 h) SAR/day (1,264,000 SAR/year) according to the local tariff exchange.

The SVM study affected achieving high points requirements for the LEED for Schools 2009 checklist from the LEED V4 rating system in the energy and atmosphere (EA) category, whereas it reached 10 points in its optimize energy performance credit, C1, and 3 points in on-site renewable energy credit, C2, with a total of 13 points out of a total of 33 points (16 points for an attempt in the design stage + 17 points for attempt in the execution stage). Table 4 illustrates the energy load reduction and LEED compliance after applying SVM.

Table 4. Energy load reduction and LEED compliance after applying SVM.

Type/Load	Energy Loads				Energy Cost Saving	LEED Compliance
	Before study kWh	After study kWh	Total energy savings kWh	Saving percentage %	Saving cost SAR/day	Energy and atmosphere
Project energy loads	15,761.30	7148.11	8613.19	45.35	34,108.23 (12 h)	Optimize energy performance, 10 points
Rooftop solar modules kWh	N/A (Not applicable)	N/A	1311	8.32	3461.04 (8 h)	On-site renewable energy, 3 points
Total	15,761.30	7148.11	9924.19	53.67	37,569.27 (13,712,783.55 S (SAR/year)	13 points/17 points in execution phase

After conducting this study, it was found that the total project budget cost reduction for all value engineering modifications in every discipline was 27.48%. This is a significant reduction from the cost budget in the tender document. The tender cost percentage before applying value engineering in this study was 36.82% in architecture, 14.16% in civil, 25.02% in electrical, and 24% in mechanical disciplines.

The cost percentage after applying value engineering in this study was 31.74% in architecture, 12.10% in civil, 13.11% in electrical, and 15.57% in mechanical disciplines. Consequently, the cost reduction after applying value engineering in this study is 5.08% in architecture, 2.06% in civil, 11.91% in electrical, and 8.43% in mechanical disciplines. Figure 8 illustrates value engineering for all disciplines' budget costs in the case study. The total demand energy in tender design was 15,761.30 kW/h, and the total demand energy after applying SVM became 7148.11 kW/h, meaning that the energy reduction reached about 8613.19 kW/day with a percentage of 45.35% and cost savings of 34,108.23 SAR/day (12 h) according to the local tariff exchange, as illustrated in Table 4.

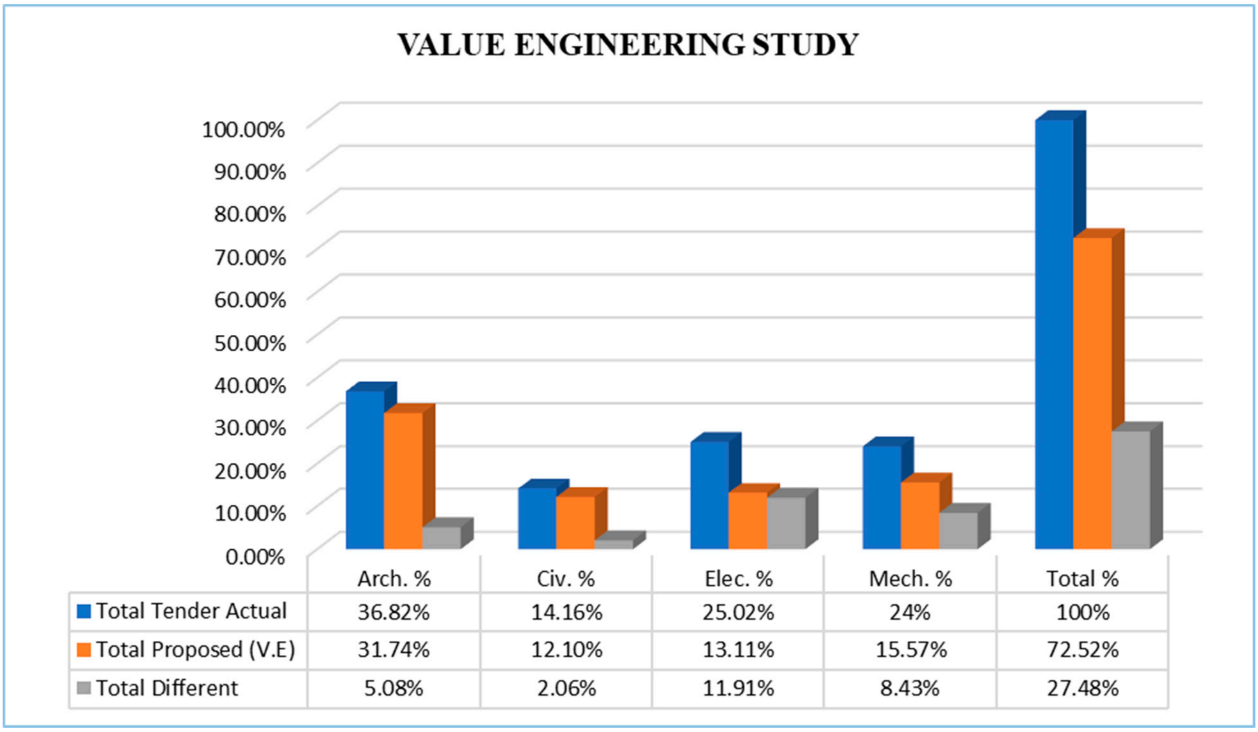

Figure 8. Value engineering for all disciplines' budget costs in the case study.

The whole result for the SVM methodology applied to the SCBG on the King Faisal University campus resulted in a total energy reduction of 9924.19 kWh (11,384,628 kW/day) (41,553,892 kW/year), representing a total 53.67% energy reduction and energy cost reduction of 37,569.27 SAR/day (13,712,783.55 SAR/year). Figure 9 summarizes the results as follows: According to the case study in its tender status before applying the sustainability-based value engineering SVM study, the project tender budget cost was 270 million SAR, the energy consumption was 1.5 MWh (60 giga W/year), and the energy cost was 22.7 million SAR/year, while there was no compatible source with the sustainability standards. The findings of the case study status after applying the sustainability-based value engineering SVM study include the project budget cost being worth 195 million SAR with a reduction cost ratio of 72.52% from the tender budget, an energy consumption of one MWh (41.5 giga W/year) with a consumption reduction ratio of 13.7% from the tender status, and the energy consumption cost worth 13 million SAR/year with a 57.27% reduction from the tender status. The findings after installing renewable energy items to comply with the requirements of the LEED for Schools 2009 checklist, which is a part of the LEED V4 rating system in sustainability, are shown below.

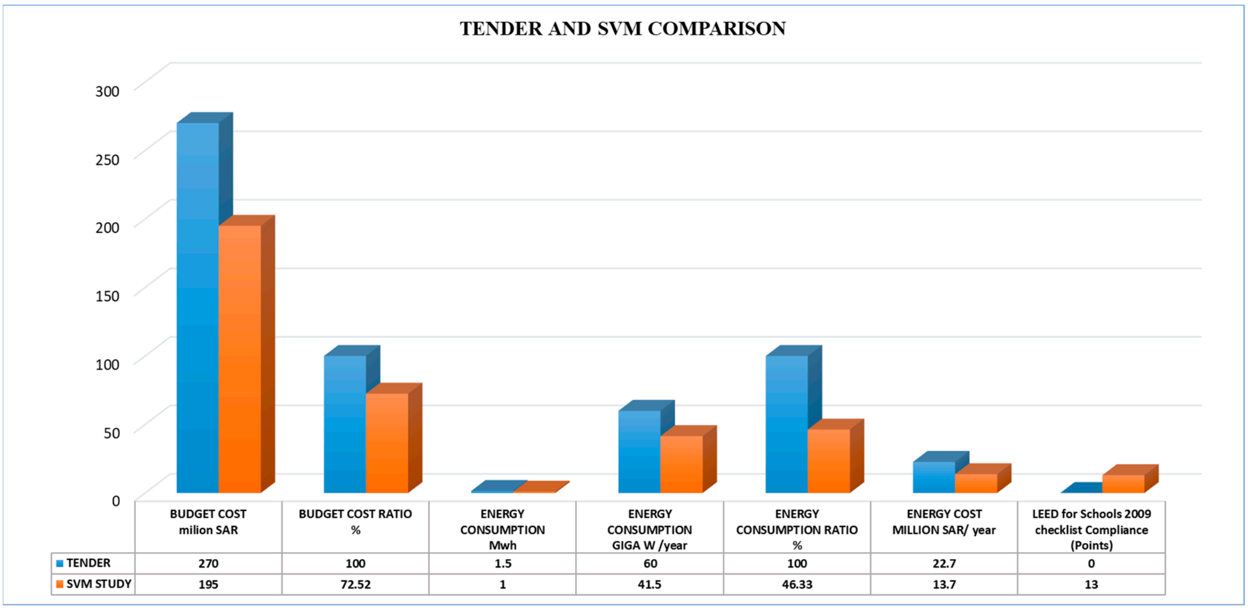

Figure 9. Study results of comparisons in the case study.

This study considered the project lifecycle's consideration and incorporation between value engineering stages and sustainability standards through the achieved benefits' potential and future potential for decision-makers, stakeholders, enterprises, and consumers. It enables practitioners to organize specific environmental, economic, and social information and data in a structured form based on all the material and system lifecycles in the case study. It also facilitates clarifying the trade-offs between the three sustainability pillars, lifecycle stages, and value engineering stage impacts along the case study lifecycle. Moreover, it promotes awareness in value chain actors on sustainability issues, enables further improvements of the case study lifecycle, i.e., energy improvements and savings, and supports decision-makers with the positive and negative impacts of resource prioritizing based on sustainable technologies, cost-efficiency, and eco-efficiency to raise case study credibility.

By reviewing more than 400 studies, we found that most of the previous research studies addressing sustainability and value engineering have focused on assessing sustainability through the project initiating stage, as well as the benefits gained in the construction project and the monitoring procedures in the building operation/maintenance stage. In contrast, few research studies addressed sustainability and value engineering in the execution processes phase. Rarely have the studies addressed a guide to integrating value engineering as lifecycle costing with sustainable development in the design phase. This study attempts to highlight integrating sustainability criteria standards with the value engineering stages through a case study to build a practical guideline to support value engineering in the evaluation stage with numerical points from sustainability categories. Therefore, the author used the case study results by applying the numerical points of the energy and atmosphere (EA) credits, which is one of the sustainable criteria standards, as the evaluating rate in the evaluation stage, which is one of the value engineering stages, to prove the benefits of this guideline matrix method, which includes addressing this guideline matrix in the local and international codes and regulations as well as practical reference procedures for decision-makers, stakeholders, enterprises, and owners working in the construction projects field to achieve sustainability criteria with savings in a cost budget. It enables practitioners in the construction project field to conduct internal evaluations for all material and system lifecycles based on specific environmental, economic, construction duration, facility maintenance, and social requirements. It also facilitates the design of a new approach for teaching curriculum in integrating value engineering stages with sustainability standards and opens gates for software designers to upgrade programs, i.e., ArchiCAD, Revit, and ArcGIS, to support students and practitioners in making robust and precise studies and applications.

These study findings have provided practical answers to the study questions and demonstrated the advantages of incorporating sustainability criteria as numerical parameters during the evaluation stage of value engineering. The results of this study offer a robust approach with a specific focus on energy-saving criteria. This approach can assist decision-makers in organizations, universities specializing in education, and the construction industry to achieve high-ranking sustainability ratings, reaching about 13 points in this study while simultaneously reducing costs. This study has also highlighted the significant benefits of merging value engineering stages with a sustainability rating system, which can lead to a 27.48% reduction in project costs and achieving 13 points in credit C1 (Optimize Energy Performance) and credit C2 (Renewable Energy Production) in the energy and atmosphere (EA) category from the LEED for Schools 2009 checklist.

5. Limitations of the Study and Directions for Future Research

These results may be limited to other public spaces of the same context according to the different conditions, i.e., nature, society culture, employee's income level, and the organization's investment vision. This study attempts to fill the gap in the existing knowledge by using numerical analysis to incorporate sustainable standard criteria in the value engineering stages to build an approach that enhances the lifecycle through a construction case study. The study enables the researchers to submit future studies on public organizations' campuses about merging value engineering systems and sustainability in different sustainability aspects, i.e., water conservation and indoor air quality.

6. Conclusions

Sustainability and value enhancement are major considerations in the modern construction industry. Therefore, the integration of sustainability standards and value engineering (VE) stages will have the potential to boost the construction project's value. This research, based on a case study, focused on highlighting the integration process between categories of the LEED for Schools 2009 checklist, which is part of the LEED V4 rating system, as a sustainable standard, as well as the value engineering stages to achieve significant findings in cost reduction, while raising sustainable credits in the energy and atmosphere (EA) category. Applying this study with a sustainability-based value engineering SVM approach to a school complex led to achieving an energy reduction of 14,184.840 kW/year, representing a 64% energy reduction, with a cost reduction of 8408.570 SAR/year. By modifying the electromechanical systems and materials as well as using rooftop solar modules, the project can earn 13 points from a total of 33 points (16 points attempted in the design stage and 17 points attempted in the execution stage) in the energy and atmosphere category. The total cost reduction after applying this study, besides the evaluation of the comprehensive value engineering in architectural, civil, mechanical, and electrical works, reaches about 27.48% of the total cost of the project budget. These study findings based on experts' interviews on case study results created guidelines for the merging approaches between sustainability and value engineering in the construction industry.

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Data Availability Statement: The data are available upon request from the first author.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

LEED v4 for BD+C: New Construction and Major Renovation
Project Checklist

Project Name:
Date:

Y	?	N			
			Credit	Integrative Process	1
0	0	0	**Location and Transportation**		**16**
			Credit	LEED for Neighborhood Development Location	16
			Credit	Sensitive Land Protection	1
			Credit	High Priority Site	2
			Credit	Surrounding Density and Diverse Uses	5
			Credit	Access to Quality Transit	5
			Credit	Bicycle Facilities	1
			Credit	Reduced Parking Footprint	1
			Credit	Green Vehicles	1
0	0	0	**Sustainable Sites**		**10**
Y			Prereq	Construction Activity Pollution Prevention	Required
			Credit	Site Assessment	1
			Credit	Site Development - Protect or Restore Habitat	2
			Credit	Open Space	1
			Credit	Rainwater Management	3
			Credit	Heat Island Reduction	2
			Credit	Light Pollution Reduction	1
0	0	0	**Water Efficiency**		**11**
Y			Prereq	Outdoor Water Use Reduction	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Building-Level Water Metering	Required
			Credit	Outdoor Water Use Reduction	2
			Credit	Indoor Water Use Reduction	6
			Credit	Cooling Tower Water Use	2
			Credit	Water Metering	1
0	0	0	**Energy and Atmosphere**		**33**
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Building-Level Energy Metering	Required
Y			Prereq	Fundamental Refrigerant Management	Required
			Credit	Enhanced Commissioning	6
			Credit	Optimize Energy Performance	18
			Credit	Advanced Energy Metering	1
			Credit	Demand Response	2
			Credit	Renewable Energy Production	3
			Credit	Enhanced Refrigerant Management	1
			Credit	Green Power and Carbon Offsets	2
0	0	0	**Materials and Resources**		**13**
Y			Prereq	Storage and Collection of Recyclables	Required
Y			Prereq	Construction and Demolition Waste Management Planning	Required
			Credit	Building Life-Cycle Impact Reduction	5
			Credit	Building Product Disclosure and Optimization - Environmental Product Declarations	2
			Credit	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
			Credit	Building Product Disclosure and Optimization - Material Ingredients	2
			Credit	Construction and Demolition Waste Management	2
0	0	0	**Indoor Environmental Quality**		**16**
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
			Credit	Enhanced Indoor Air Quality Strategies	2
			Credit	Low-Emitting Materials	3
			Credit	Construction Indoor Air Quality Management Plan	1
			Credit	Indoor Air Quality Assessment	2
			Credit	Thermal Comfort	1
			Credit	Interior Lighting	2
			Credit	Daylight	3
			Credit	Quality Views	1
			Credit	Acoustic Performance	1
0	0	0	**Innovation**		**6**
			Credit	Innovation	5
			Credit	LEED Accredited Professional	1
0	0	0	**Regional Priority**		**4**
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
0	0	0	**TOTALS**	**Possible Points:**	**110**

Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80 to 110

LEED for School 2009 checklist from LEED V4 rating system

0	0	0		**Energy and Atmosphere**			**le Points:**	**33**
Y	**?**	**N**						
Y			C	**Prereq 1**	**Fundamental Commissioning of Building Energy Systems**			
Y			d	**Prereq 2**	**Minimum Energy Performance**			
Y			d	**Prereq 3**	**Fundamental Refrigerant Management**			
			d	**Credit 1**	**Optimize Energy Performance**			**1 to 19**
						Improve by 12% for New Buildings or 8% for Existing Building Renovations		**1**
						Improve by 14% for New Buildings or 10% for Existing Building Renovations		**2**
						Improve by 16% for New Buildings or 12% for Existing Building Renovations		**3**
						Improve by 18% for New Buildings or 14% for Existing Building Renovations		**4**
						Improve by 20% for New Buildings or 16% for Existing Building Renovations		**5**
						Improve by 22% for New Buildings or 18% for Existing Building Renovations		**6**
						Improve by 24% for New Buildings or 20% for Existing Building Renovations		**7**
						Improve by 26% for New Buildings or 22% for Existing Building Renovations		**8**
						Improve by 28% for New Buildings or 24% for Existing Building Renovations		**9**
						Improve by 30% for New Buildings or 26% for Existing Building Renovations		**10**
						Improve by 32% for New Buildings or 28% for Existing Building Renovations		**11**
						Improve by 34% for New Buildings or 30% for Existing Building Renovations		**12**
						Improve by 36% for New Buildings or 32% for Existing Building Renovations		**13**
						Improve by 38% for New Buildings or 34% for Existing Building Renovations		**14**
						Improve by 40% for New Buildings or 36% for Existing Building Renovations		**15**
						Improve by 42% for New Buildings or 38% for Existing Building Renovations		**16**
						Improve by 44% for New Buildings or 40% for Existing Building Renovations		**17**
						Improve by 46% for New Buildings or 42% for Existing Building Renovations		**18**
						Improve by 48%+ for New Buildings or 44%+ for Existing Building Renovations		**19**
			d	**Credit 2**	**On-Site Renewable Energy**			**1 to 7**
						1% Renewable Energy		**1**
						3% Renewable Energy		**2**
						5% Renewable Energy		**3**
						7% Renewable Energy		**4**
						9% Renewable Energy		**5**
						11% Renewable Energy		**6**
						13% Renewable Energy		**7**
			C	**Credit 3**	**Enhanced Commissioning**			**2**
			d	**Credit 4**	**Enhanced Refrigerant Management**			**1**
			C	**Credit 5**	**Measurement and Verification**			**2**
			C	**Credit 6**	**Green Power**			**2**

The evaluation stage process details for Energy and Atmosphere

COMPLIANCE SPREADSHEET				
ENERGY TARGET	ENERGY CONSUMPTION		TECHNICAL PROCEDURES	OFFICIAL CONTRACTURAL PROCEDURES
	BEFORE STUDY	AFTER STUDY		

Register the points results gained for each accepted item in spreadsheet

Figure A1. Sustainable and value engineering management approach SVM.

Zone Sizing Summary for FAN COIL (PROJECT SPECIFICATIONS

Project Name: Glass load comparison (B01) 05/06/2021
Prepared by: ZFP 09:40AM

Air System Information

Air System Name **FAN COIL (PROJECT SPECIFICATIONS**
Equipment Class **TERM**
Air System Type **4P-FC**

Number of zones **1**
Floor Area **29.0** m²
Location **AL AHSA, Saudi Arabia**

Sizing Calculation Information

Zone and Space Sizing Method:

Zone L/s **Sum of space airflow rates**
Space L/s **Individual peak space loads**

Calculation Months **Jan to Dec**
Sizing Data **Calculated**

Zone Sizing Data

Zone Name	Maximum Cooling Sensible (kW)	Design Air Flow (L/s)	Minimum Air Flow (L/s)	Time of Peak Load	Maximum Heating Load (kW)	Zone Floor Area (m²)	Zone L/(s-m²)
Zone 1	3.5	269	269	Jul 1500	0.8	29.0	9.29

Terminal Unit Sizing Data - Cooling

Zone Name	Total Coil Load (kW)	Sens Coil Load (kW)	Coil Entering DB / WB (°C)	Coil Leaving DB / WB (°C)	Water Flow @ 8.0 °K (L/s)	Time of Peak Load
Zone 1	5.5	3.7	25.1 / 19.1	13.6 / 13.1	0.16	Jun 1600

Terminal Unit Sizing Data - Heating, Fan, Ventilation

Zone Name	Heating Coil Load (kW)	Heating Coil Ent/Lvg DB (°C)	Htg Coil Water Flow @15.0 °K (L/s)	Fan Design Airflow (L/s)	Fan Motor (BHP)	Fan Motor (kW)	OA Vent Design Airflow (L/s)
Zone 1	0.8	20.8 / 23.4	0.01	269	0.000	0.000	52

Space Loads and Airflows

Zone Name / Space Name	Mult.	Cooling Sensible (kW)	Time of Load	Air Flow (L/s)	Heating Load (kW)	Floor Area (m²)	Space L/(s-m²)
Zone 1							
EI-WD-0260 (PROJECT)	1	3.5	Jul 1500	269	0.8	29.0	9.29

Hourly Analysis Program v4.50 Page 1 of 1

Figure A2. Sample of air-system sizing in the study.

Table A1. The idea number and descriptions.

Idea Number	Idea Description
Idea (7)	Administration tower cancelation and redesign elevators and waiting areas
Idea (8)	Modification of the space dimensions specialized for open courts
Idea (10)	Reduction in the administration tower height
Idea (12)	Cancelation of the basement in the administration tower of the library and moving it to the ground floor
Idea (15)	Reduction in the number of computer labs based on international standards and replacing them with classrooms
Idea (17)	Re-coordination of the playground site at the primary school
Idea (18)	Reduction in the number of administration offices at the primary school
Idea (22)	Redistribution of administration offices based on the standards of intermediate, secondary, and primary schools
Idea (24)	Re-studying the entrance of the primary school and re-coordinating the external opening of the intermediate, secondary, and primary schools
Idea (26)	Cancelation of the canteen located in the inner courtyard of the intermediate, secondary, and primary schools
Idea (27)	Creation of a cafeteria overlooking the outer areas of the intermediate and secondary schools
Idea (28)	Studying the path of the decorative wall columns that contradict the inner courtyard of the intermediate and secondary schools
Idea (30)	Increasing the number of toilets based on modifying the number of classes
Idea (31)	Creation of a cafeteria instead of the canteen at the primary school
Idea (35)	Reducing the height of the decorative wall
Idea (41)	Cancelation of the gym cafeteria in the mezzanine and ground floors
Idea (44)	Replacing the space between the start of the two walls and the gym spaces as service rooms
Idea (45)	Adding spaces for showers and changing areas in the gym
Idea (48)	Cancelation of the electricity room next to the intermediate building due to its impact on the external façade
Idea (49)	Creating an electricity room inside the gym, next to the western entrance of the hall
Idea (51)	Re-studying the design of the external landscaping of the school complex after the site change
Idea (54)	Adding a swimming pool in the gym
Idea (56)	Correcting the spaces for the guards
Idea (57)	Adding a space for the air-handling units (AHU) above the area of the electric boards inside the gym
Idea (59)	Creating a space for parents' reception and a restroom for teachers

Appendix B

Table A2. Architectural Items—Development Ideas.

Ideas	Based on Value Engineering			Based on Tender		
	Description	Unit	Quantity	Description	Unit	Quantity
1	Riyadh stone 8 cm thick	M^2	2512	Printed concrete	M^2	1137
2	Sustainable poly. containers	Pcs	15	Concrete garbage containers	Pcs.	50
3	Homogenous antistatic vinyl	L.M	6578	Marble skirting	L.M	1017
4	Painting external walls	M^2	10,290	External paintings	M^2	7000
5		M^2		GRC external cladding	M^2	6691
6	Glass curtains	M^2	37	Glass curtains	M^2	104
7	Vinyl floorings	M^2	11,213	Polyurethane floorings	M^2	9033
8	Solid cement walls	M^2	2700	Solid cement walls	M^2	15,128

Table A3. Civil Items—Development Ideas.

Ideas	Based on Value Engineering			Based on Tender		
	Description	Unit	Quantity	Description	Unit	Quantity
1	Excavation	M^3	30,000	Excavation	M^3	12,525
2	Backfilling with sand	M^3	10,000	Backfilling with sand	M^3	16,500
3	Backfilling A-1b	M^3	10,000	Backfilling A-1b	M^3	13,000
4	Lean concrete for ground tiles	M^3	2400	Lean concrete for ground tiles	M^3	0
5	Lean concrete under foundations and ground beams	M^3	800	Lean concrete under foundations and ground beams	M^3	400
6	Reinforced concrete for flooring tiles	M^3	0	Reinforced concrete for flooring tiles	M^3	1200
7	Reinforced concrete for foundations	M^3	2860	Reinforced concrete for foundations	M^3	2000
8	Reinforced concrete for columns and walls	M^3	2660	Reinforced concrete for columns and walls	M^3	2150
9	Reinforced concrete for tiles and stairs	M^3	3066	Reinforced concrete for tiles and stairs	M^3	2800
10	Reinforced concrete for beams	M^3	1180	Reinforced concrete for beams	M^3	750
11	Reinforced concrete of ground bridges	M^3	720	Reinforced concrete of ground bridges	M^3	600
12	Polystyrene blocks for hollow block slab	M^3	100	Polystyrene blocks for hollow block slab	M^3	0
13	Foundation insulation	M^2	14,800	Foundation insulation	M^2	13,800
14	Humidity insulation	M^2	3470	Humidity insulation	M^2	13,000
15	Cavity detection	L.M	1000	Cavity detection	L.M	700
16	Cavity treatment	Ton	755	Cavity treatment	Ton	0

Table A4. Electrical Items—Development Ideas.

Ideas	Based on Value Engineering			Based on Tender		
	Description	Unit	Quantity	Description	Unit	Total
1	Medium voltage, including transformers, 1500 kVA	Num.	2,540,000	Medium voltage, including transformers, 1500 kVA	Num.	1,570,000
2	General and subsidiary low-pressure plates 400/230 V, M.C.C.B circuits	LM	1,988,000	General and subsidiary low-pressure containers 400/230 V, M.C.C.B circuits	LM	696,000
3	Copper cables of 600/1000 V CU/XLPE/PVC	LM	6,283,250	Copper cables of 600/1000 V CU/XLPE/PVC	LM	3,565,600
4	Interior lighting units	Num.	6,006,380	Interior lighting units	Num.	2,144,630
5	Supply, installation, testing, and operating data network and cables (CAT6A)	LS		Supply, installation, testing, and operating data network and cables (CAT6A)	LS	
6	Passive components of data port Giga SPEED 10 d modular patch panel	Num.	1,327,650	Passive components of data port Giga SPEED 10 d modular patch panel	Num.	217,750
7	Active components, data key, 48 ports	Num.	1,980,800	Active features, data key, 48 ports	Num.	691,200
8	Safety lighting system		1,674,200	Safety lighting system		
9	Clock system		242,500	Clock system		175,000
10	Audio/visual system		4,145,000	Audio/visual system		1,478,000
11	Lighting control system with EIB-KNX	Num.	2,468,820	Lighting control system with EIB-KNX	Num.	811,000
12	Solar energy as an alternative		0	Solar energy as alternatives	Num.	800,000
13	Fire alarm system		1,237,420	Fire alarm system		653,300

Table A5. Mechanical Items—Development Ideas.

Ideas	Based on Value Engineering			Based on Tender			
	Description	Unit	Quantity	Item	Description	Unit	Quantity
1	Frozen water pumps	Pcs.	20		Frozen water pumps	Pcs.	6
2	9-gallon pump, makeup pump. WP-M	Pcs.	8		9-gallon pump–makeup pump. WP-M	Pcs.	2
3	Air-handling units (AHU)	Pcs.	47		Air-handling units (AHU)	Pcs.	23
4	Fan coil units	Pcs.	121		Fan coil units	Pcs.	167
5	Fans	Pcs.	124		Fans	Pcs.	34
6	Spiral ducts	Kg	45,000		Cloth ducts	L.M	265
7	Chillers units	Pcs.	10		Chillers units	Pcs.	4
8	Expanding tanks	Pcs.	10		Expanding tanks	Pcs.	1
9	Replacement of cold water pumps	Pcs.	8		Cold water pumps	Pcs.	2
10	Replacement of fiberglass tanks	Pcs.	36		10 m^3-polyethylene tanks	Pcs.	8
11	Replacement of FM200 with Co^2	Pcs.	36		Replacement of FM200 with Co^2	Pcs.	3
12	Cancelation of alarm check valve	Pcs.	29		Black iron cooling water pipes 10″ thick	LM	50
13	Cancelation of 2 tap-water cooler	Pcs.	13		RTR cooling water pipes 8″ thick	LM	400
14	Reducing iron sheets	Kg	81,000		some air-handling units (AHU) to fan coil	kg	60,000
15	Cancelation of 10-person elevator	Pcs.	1				
16	Cancelation of heaters	Pcs.	13				
17	Cancelation of hot water pumps	Pcs.	8				

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