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VEIDEA: A Comprehensive Framework for Implementing Building Information Modeling-Based Value Engineering Within a Common Data Environment in Construction Projects

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Abstract: The Architecture, Engineering, and Construction (AEC) industry faces significant global challenges, including frequent project delays, budget overruns, and inadequate stakeholder collaboration. To address these issues, Value Engineering (VE) and Building Information Modeling (BIM) have been increasingly used in large-scale, complex construction projects. Although many studies highlight the benefits of integrating VE with BIM, its full practical potential has not yet been realized. This study aims to investigate the integration of VE and BIM within a Common Data Environment (CDE) to improve decision making and project outcomes. A comprehensive framework was developed, consisting of four interconnected modules: (1) Creating the CDE, (2) Developing the BIM Model, (3) Implementing Value Engineering, and (4) Conducting a Value Engineering Study. Central to this framework is the introduction of the VEIDEA" data bank, a structured system based on the OmniClass classification, which stores and organizes VE ideas. Additionally, the framework incorporates the Analytical Hierarchy Process (AHP) to automate the evaluation phase, assisting designers and VE teams in making data-driven decisions on design alternatives. Empirical results from a case study of an office building show significant cost savings, with a 20% reduction in reinforced concrete (RC) slab costs and a 39% reduction in flooring material costs. These findings demonstrate the potential for integrating VE and BIM to enhance cost-effectiveness and overall project performance. This study offers a novel approach to optimizing project collaboration, decision making, and efficiency in the AEC industry.

Keywords: value engineering (VE); building information modeling (BIM); common data environment (CDE); VE idea bank; analytic hierarchy process (AHP); construction projects

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1. Introduction

The Architecture, Engineering, and Construction (AEC) industry is undergoing a profound digital transformation, largely driven by the need for greater efficiency, cost-effectiveness, and enhanced project value [1]. Project value is often measured as the ratio between functionality and cost, a critical factor in construction activities that are frequently plagued by budget overruns and delays [2]. To address these challenges and improve project outcomes, two methodologies—Value Engineering (VE) and Building Information Modeling (BIM)—have garnered significant attention in recent literature.

Value Engineering has long been recognized as a systematic and innovative approach for enhancing project value by reducing costs while optimizing performance [3]. It involves a multidisciplinary team that evaluates project requirements, generates alternatives, and selects the most efficient solutions to achieve desired functionalities at minimal cost. A review of VE literature highlights that its success is closely tied to effective communication and structured collaboration among project stakeholders, which underscores the importance of coordinated activities for achieving optimal outcomes.

Similarly, Building Information Modeling (BIM) is heralded as a transformative technology within the AEC industry, known for its capacity to produce comprehensive digital representations of buildings [4]. BIM facilitates improved planning, design, construction, and operation processes, significantly boosting efficiency and productivity, particularly during the design phase. Despite its recognized advantages, BIM adoption, especially among small and medium-sized enterprises (SMEs), faces several barriers that need to be carefully considered for broader implementation [5].

The integration of VE and BIM presents a valuable opportunity to advance project management practices in the AEC sector. While both methodologies have proven benefits individually, the synergistic potential of integrating them remains underexplored. Few studies have examined the combined effects of VE and BIM on construction projects, and there is a noticeable lack of frameworks guiding their effective integration [6,7]. This gap represents a critical opportunity for advancing both research and practical applications in the field.

In response to this research and practice gap, this study aims to develop a comprehensive framework for integrating VE and BIM within a Common Data Environment (CDE) to optimize construction project outcomes. The proposed framework will offer AEC professionals a structured approach for applying VE in conjunction with BIM, ultimately enabling better cost management and enhanced project performance. By bridging the gap between the theoretical potential of these methodologies and their practical implementation, this study seeks to provide practitioners with the tools necessary to fully leverage the benefits of VE–BIM integration. Moreover, the framework is expected to lay the foundation for future research and development, contributing to significant advancements in project management practices within the construction industry.

In the following section, a bibliometric analysis of VE–BIM integration will be presented, providing a comprehensive overview of the current research. Subsequently, the fundamental concepts of Value Engineering, BIM, classification systems, and the application of a Common Data Environment (CDE) in construction projects will be introduced. Then, the proposed framework for BIM-based Value Engineering within a CDE, which is the core this research, will be explained in detail. Finally, a case study will be used to demonstrate the application of the proposed framework process.

2. A Bibliometric Analysis of VE–BIM Integration

A bibliometric analysis was conducted using Visualization of Similarities Viewer (VOSviewer) to create bibliometric maps, focusing on the integration between VE and BIM. Keyword co-occurrence analysis of the data was retrieved from the Scopus database. The analysis was used to identify the emerging related topics. The analysis included all keywords available in the retrieved publications, and a threshold of five was set as the minimum number of keywords. A total of 22 of the 582 keywords met the criteria. Figure 1 shows the network of high-frequency keywords. The network shows that the keyword “Building information modeling” is the most significant node, followed by the keywords “Value engineering” and “Architectural design”. These keywords are commonly associated with keywords such as “Construction Projects”, “Project Management”, “Cost Estimating”, “Budget Control”, and “Information Management”. This suggests that VE and BIM are frequently used in these research areas. Consequently, BIM integration can help manage the construction project’s cost and information. This analysis provides a foundational understanding of the current research landscape, guiding the focus of our study and highlighting the critical areas where VE–BIM integration can contribute significantly.

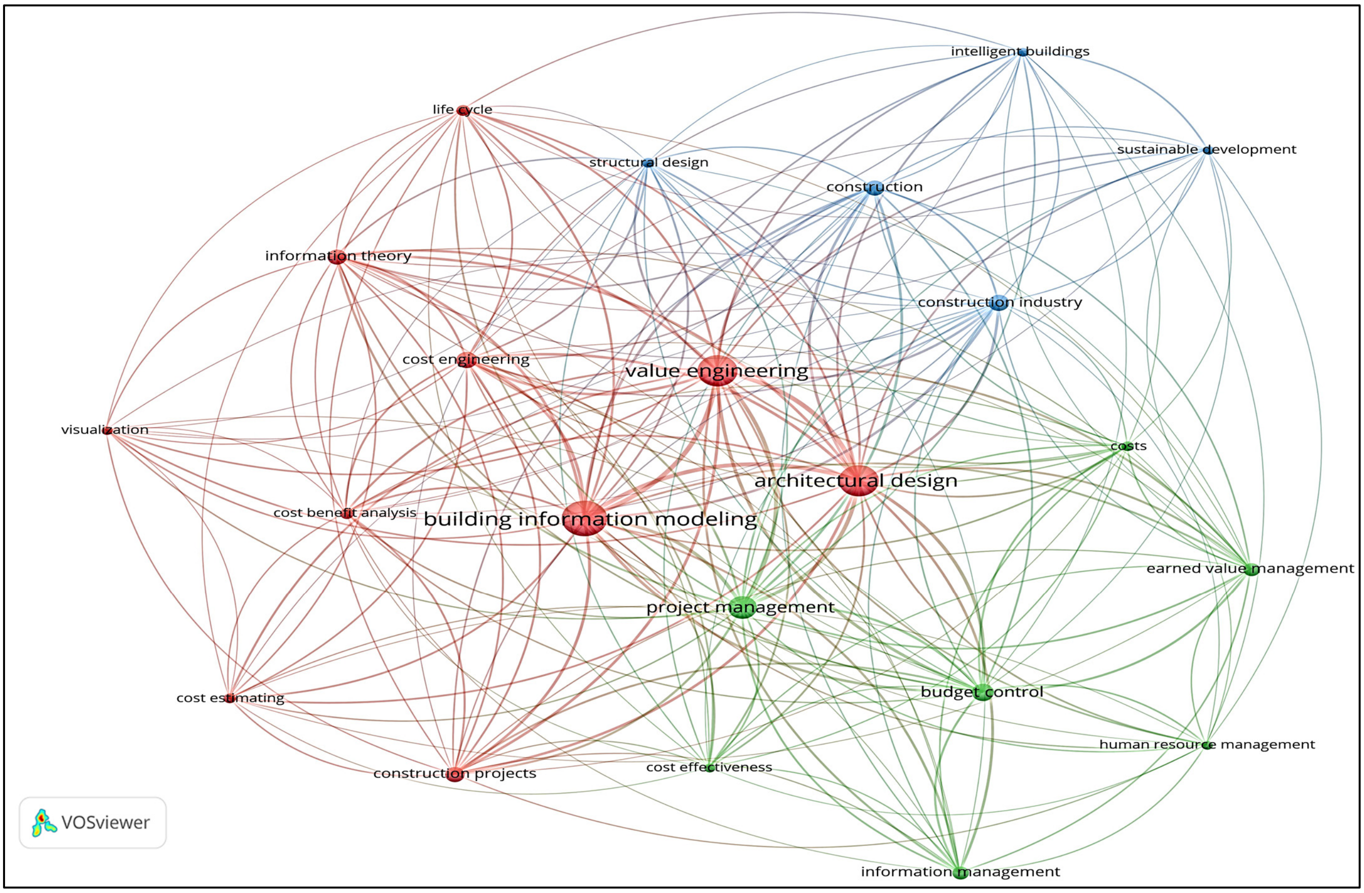

Figure 1. The keywords' co-occurrence network by VOSviewer.

3. Value Engineering

Value Engineering (VE) is a structured methodology aimed at optimizing project value by enhancing function or performance while minimizing costs. In the Architecture, Engineering, and Construction (AEC) industry, VE is traditionally implemented through a multi-phase job plan that examines project elements to identify cost-saving opportunities without compromising functionality. The VE process follows the Society of American Value Engineers (SAVE) standard job plan, consisting of five interdependent phases: information, function analysis, creativity, evaluation, and development, culminating in the presentation phase. Each phase builds on the previous one, ensuring a thorough analysis that systematically addresses the project's functional requirements [8]. The data collected during the information phase is especially crucial, as it informs all subsequent phases of the VE study. By systematically applying VE, project teams can enhance overall project quality, performance, safety, and durability [9].

In VE, value is defined as the ratio between function and cost, and three primary approaches are used to optimize it. The Accepted Approach involves increasing function while maintaining a constant cost or reducing costs without sacrificing functionality. The Negotiable Approach allows for some flexibility, accepting a slight increase in cost for a significant improvement in function or tolerating a slight reduction in function for substantial cost savings. The Ideal Approach, considered the most desirable, seeks to simultaneously reduce costs and improve functionality, thereby maximizing value on both fronts [9].

4. The Concept of BIM

Building Information Modeling (BIM), initially conceptualized by Charles M. Eastman in the 1980s and 1990s, is a process that integrates geometric and process-related information to facilitate collaborative project management throughout the lifecycle of a construction project [10]. Also referred to as Building Information Management [11], BIM provides a digital representation of all building characteristics and associated data, allowing stakeholders to access and update information in real time. This integrated approach not only captures the physical geometry of building components but also their functional parameters [12]. As team members refine the model based on design changes and project specifications, BIM ensures that accurate data are available before the construction phase. The finalized BIM model enables precise quantity take-offs, component counts, construction scheduling, and spatial analysis, offering a comprehensive data repository that informs decision making throughout the project [13].

4.1. BIM Implementation in the Construction Industry

BIM has revolutionized construction practices by improving collaboration, reducing design errors, and streamlining documentation. Its primary goal is to optimize project outcomes by minimizing costs, shortening timelines, reducing waste, and enhancing overall quality and productivity. The versatility of BIM allows it to be implemented at all stages of a project, enabling stakeholders—including owners, consultants, and contractors—to manage various aspects of construction more efficiently. Owners can better comprehend the project scope, while consultants use BIM for analysis, design, and development. Contractors benefit from BIM's capabilities in project planning and management [14].

To address challenges such as integrating BIM models created by different project participants, a BIM-enabled lifecycle information management framework is proposed [15]. This framework coordinates the dynamic and fragmented data flows throughout the project lifecycle, ensuring that the information is consistent and aligned with different project phases. Figure 2 demonstrates the detailed application of BIM in lifecycle information management, highlighting how it streamlines data integration and enhances project coordination.

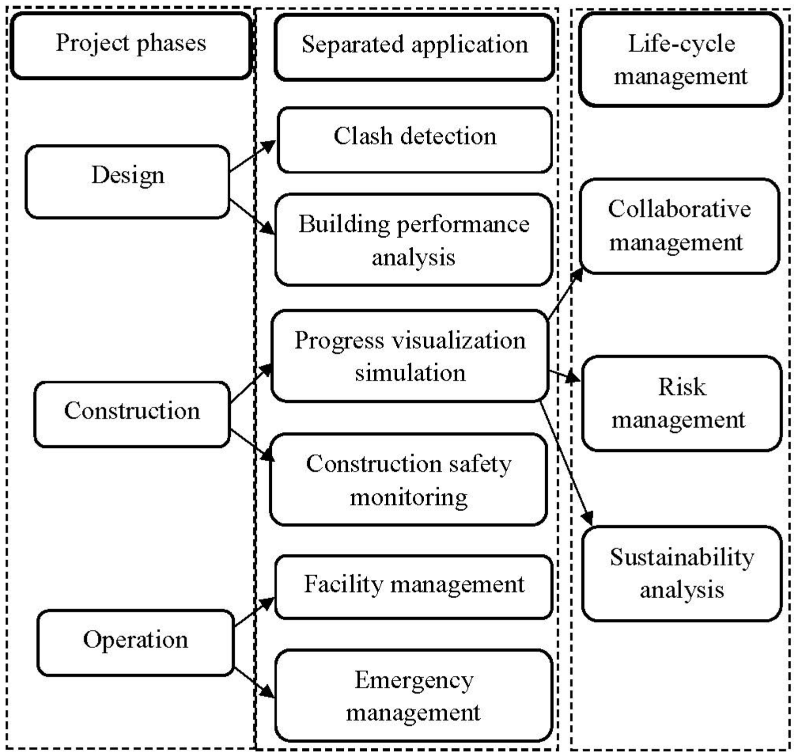

Figure 2. Detailed application of BIM in life-cycle information management [15].

BIM's intelligent management capabilities are particularly valuable in complex construction projects, helping to manage stakeholder expectations and mitigate risks such as cost overruns and delays [16]. Its emphasis on feedback loops and precision makes it a critical tool for successful project management, as it allows for the seamless transfer of data among stakeholders and supports the development of comprehensive solutions [17].

4.2. Benefits of BIM Implementation for Value Engineering

In recent years, leading firms in the Architecture, Engineering, and Construction (AEC) industry have recognized the benefits of BIM, transitioning from traditional Computer-Aided Design (CAD) systems to BIM technology [18]. BIM's collaborative capabilities across multiple disciplines have enhanced its value as a tool for optimizing construction projects. When combined with Value Engineering (VE), BIM provides significant benefits by improving project efficiency, enhancing decision making, and optimizing costs. By offering a comprehensive representation of a building's physical and functional characteristics, BIM aligns with VE's objectives of maximizing project value through cost reduction and performance improvement [19].

The main benefit of BIM implementation is its ability to provide an accurate three-dimensional (3D) geometrical representation of a building within an integrated data environment [12]. Some of the key benefits of using BIM for Value Engineering include:

- Enhanced collaboration and communication: BIM improves interaction among project stakeholders, ensuring that all team members work with the most current information [20].
- Increased efficiency and productivity: by reducing rework during the construction phase, BIM enhances overall project productivity [21].
- Sustainability and waste reduction: BIM facilitates the selection of sustainable materials and reduces material waste, contributing to environmentally friendly practices [22].
- Integrated tracking systems: BIM enables the creation of tracking systems to analyze workplace behavior and improve efficiency [23].
- Dynamic data integration: by incorporating existing conditions, sensor measurements, and control signals, BIM enhances the analysis of building operations and maintenance [24].
- Improved decision making: BIM's ability to identify design and construction issues early in the process improves overall decision making and reduces risks.

4.3. BIM Level of Development (LOD)

The Level of Development (LOD) refers to the degree of detail and reliability of the geometric and semantic information in a BIM project. This concept reflects the incremental availability of data throughout the design stages. The LOD plays a critical role in BIM execution plans (BEP) [25], and it is often a contractually binding specification in construction projects [26]. The American Institute of Architects (AIA) introduced the LOD in 2008, defining five levels, ranging from LOD 100 (Conceptual Design) to LOD 500 (As-Built). In 2013, the BIM-Forum working group expanded on the AIA definitions by introducing LOD 350, and it continues to update these specifications annually. Table 1 summarizes the different LOD levels as defined by the BIM-Forum.

Table 1. BIM Levels of Development [27].

Level of Development (LOD)	Description
LOD 100 (Conceptual Design)	Model elements are represented graphically in a generic representation.
LOD 200 (Schematic Design)	The model elements are represented as a generic object with approximate quantities, location, shape, size, and orientation.
LOD 300 (Detailed Design)	Model elements are precisely modeled with their exact quantities, location, shape, size, and orientation.

Table 1. *Cont.*

Level of Development (LOD)	Description
LOD 350 (Construction Documentation)	Including the interfaces between all the building systems.
LOD 400 (Fabrication and Assembly)	The model includes information related to detailing, fabrication, assembly, and installation.
LOD 500 (As-Built)	The model elements are verified representations of the construction site in terms of quantities, location, shape, size, and orientation.

5. Classification Systems for Construction Projects

Efficient communication and information management are critical for successful execution of construction projects. Classification systems play a pivotal role in organizing the vast amounts of data generated throughout a project's lifecycle, enabling easy access to essential information and facilitating collaboration among project participants.

A well-structured classification system brings order to otherwise disorganized project data, allowing stakeholders to retrieve, filter, and present information in a way that makes sense to the recipient. This is particularly important in the context of BIM and VE, where data must be organized and accessible to support informed decision making.

The OmniClass classification system has been widely adopted in the construction industry to organize project information across various categories. Its primary application is to provide a structured classification for electronic databases and software, thereby enhancing data utilization within these resources [28]. The compatibility of OmniClass with other classification systems, such as MasterFormat and UniFormat, further extends its utility, allowing for seamless integration of multiple data sources into BIM models [29].

In this study, the OmniClass classification system served as the backbone for the VEIDEA data bank. This data bank organizes Value Engineering (VE) ideas using OmniClass's structured tables, such as Table 13 (Spaces by Function), which is shown in Figure 3, Table 21 (Elements), Table 22 (Work Results), and Table 41 (Materials). By categorizing VE ideas within this framework, the VEIDEA data bank allows for targeted searches and the efficient retrieval of relevant design alternatives during the VE process. This structured approach not only saves time but also ensures that past VE ideas are readily accessible for integration into ongoing projects.

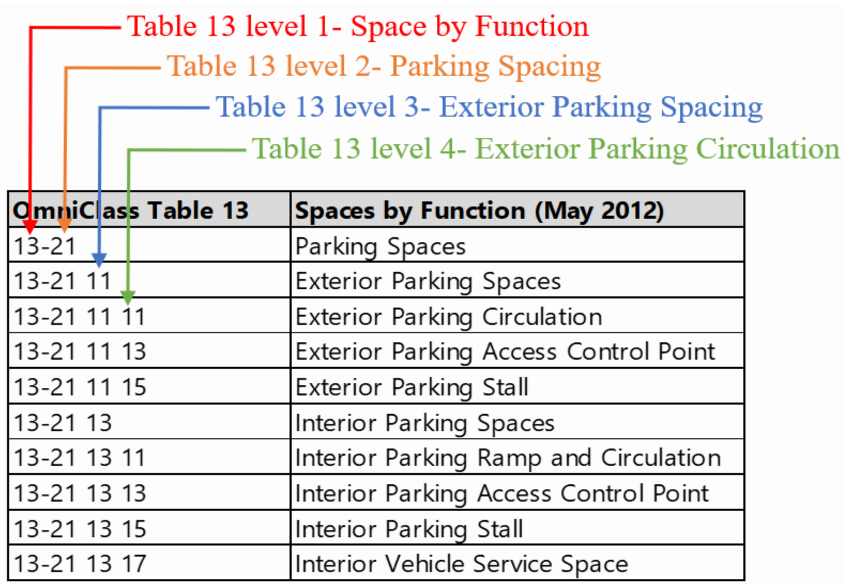

Figure 3. Example of OmniClass classification, Table 13 (Space by Function).

The use of OmniClass within a Common Data Environment (CDE) further enhances the ability to manage and coordinate project information across all stakeholders. By aligning data organization with lifecycle stages and project requirements, OmniClass supports a more cohesive and efficient project management process. This integration ensures that all project participants have access to the most up-to-date information, reducing the risk of miscommunication and facilitating better decision making throughout the project lifecycle.

6. Leveraging CDE in Construction Projects

The Common Data Environment (CDE) serves as a centralized platform for managing and sharing information across the lifecycle of construction projects [30]. The workflow of the CDE in Figure 4 illustrates the various statuses of information containers.

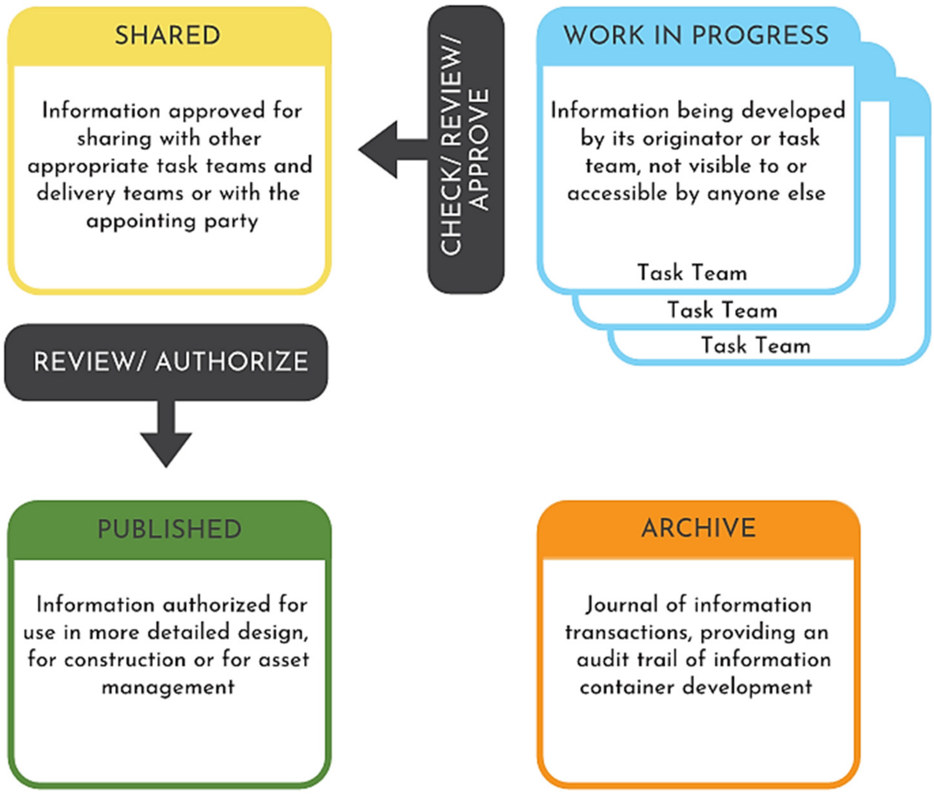

Figure 4. The workflow of the CDE [30].

1. The Work-in-Progress (WIP) state.
2. The Shared state.
3. The Published Documentation state.
4. The Archive states.

In the context of integrating Building Information Modeling (BIM) and Value Engineering (VE), the CDE plays a critical role in enhancing collaboration, streamlining data management, and improving decision making processes among all project stakeholders. The CDE facilitates seamless communication and coordination among diverse project teams by providing a single source of truth for all project-related information [31]. This centralized repository ensures that every stakeholder has access to the most current and accurate data, reducing the risk of miscommunication and enabling real-time collaboration. By integrating BIM models and VE data within the CDE, project teams can work together more effectively and share updates and revisions in a controlled and transparent manner.

One of the key advantages of utilizing a CDE in construction projects is its ability to support the Value Engineering process. A CDE enables the structured storage and retrieval of VE ideas, particularly when combined with classification systems such as OmniClass.

During the VE study phase, team members could easily access historical data, evaluate previous VE alternatives, and implement the most cost-effective solutions in the BIM model. This integration not only saves time but also enhances the quality of decision making by providing a comprehensive view of all available options.

The CDE also streamlines the workflow of construction projects by automating several key processes. For instance, the CDE can facilitate the automatic updating of BIM models with VE adjustments, ensuring that all design changes are reflected in real time. This dynamic approach allows for the continuous monitoring of project progress and enables the early identification of potential issues, which can be addressed proactively.

Moreover, the CDE's ability to manage complex datasets and support multi-criteria decision making tools such as the Analytic Hierarchy Process (AHP) ensures that project teams can prioritize alternatives based on comprehensive evaluations. This systematic decision making approach is crucial for optimizing project outcomes and aligning them with client requirements and project objectives.

7. The Proposed Framework for BIM-Based Value Engineering Within a Common Data Environment (CDE)

The proposed framework integrates Building Information Modeling (BIM) with Value Engineering (VE) within a Common Data Environment (CDE), focusing on enhancing project outcomes by improving decision making, reducing costs, and ensuring that project goals align with client requirements. This framework was specifically designed to be implemented during the pre-construction phase, where the impact of design decisions is most significant. In the pre-construction phase, it is crucial that the stakeholders and design teams work cooperatively to prevent common design issues, such as changes in design, clashes between elements, constructability problems with the proposed design, and inadequate 2D drawings [32].

The proposed framework was implemented in a prototype model developed to support the VE team in evaluating and ranking different design alternatives for project components using multi-attribute criteria. Aside from the 3D geometrical model, it uses AHP to assist the VE team in evaluating competing alternatives. The project BIM model was created using Autodesk software (Revit 2024) and was used to create the 3D model and extract the required project data. The proposed method is intended to assist VE team members in performing the evaluation process with relative ease and in less time. Furthermore, it enables them to understand the consequences of alternative changes visually and numerically. Figure 5 summarizes the framework implementation sequence.

The framework was structured into four main modules, as shown in Figure 6. Each addresses a critical aspect of the VE–BIM integration process within a CDE:

1. Module 1—Creating the CDE: The first module involves establishing a CDE to serve as the single source of truth for all project-related information. The CDE securely stores all documents, BIM models, and VE ideas, ensuring that stakeholders can access the most current data. This centralized repository not only facilitates collaboration but also supports the efficient management and retrieval of information throughout the lifecycle of the project.
2. Module 2—Design BIM Model Development: The second module focuses on developing a detailed BIM model up to LOD 300, incorporating all necessary geometric and semantic data. This model serves as the foundation for VE analysis and is enriched with parameters related to the OmniClass classification system. By integrating these classifications into the BIM, the framework enhances the ability to conduct targeted searches and apply relevant VE ideas.
3. Module 3—Value Analysis/Engineering Model: In this module, the VE team uses the BIM model and CDE to evaluate and rank different design alternatives based on multi-criteria decision making. The Analytical Hierarchy Process (AHP) is employed to automate the evaluation, allowing for the systematic comparison of alternatives.

The VEIDEA data bank, which stores past VE ideas, is a key resource in this process, enabling the team to leverage historical data to inform the current decisions.

4. Module 4—Value Engineering Study: The final module streamlines the VE study by utilizing integrated BIM and CDE resources. The VE team can easily access all the necessary information, generate innovative alternatives, and assess the impact of the proposed changes on the project's overall value. The framework's use of BIM visualization tools enhances the team's ability to understand and refine design options before construction begins.

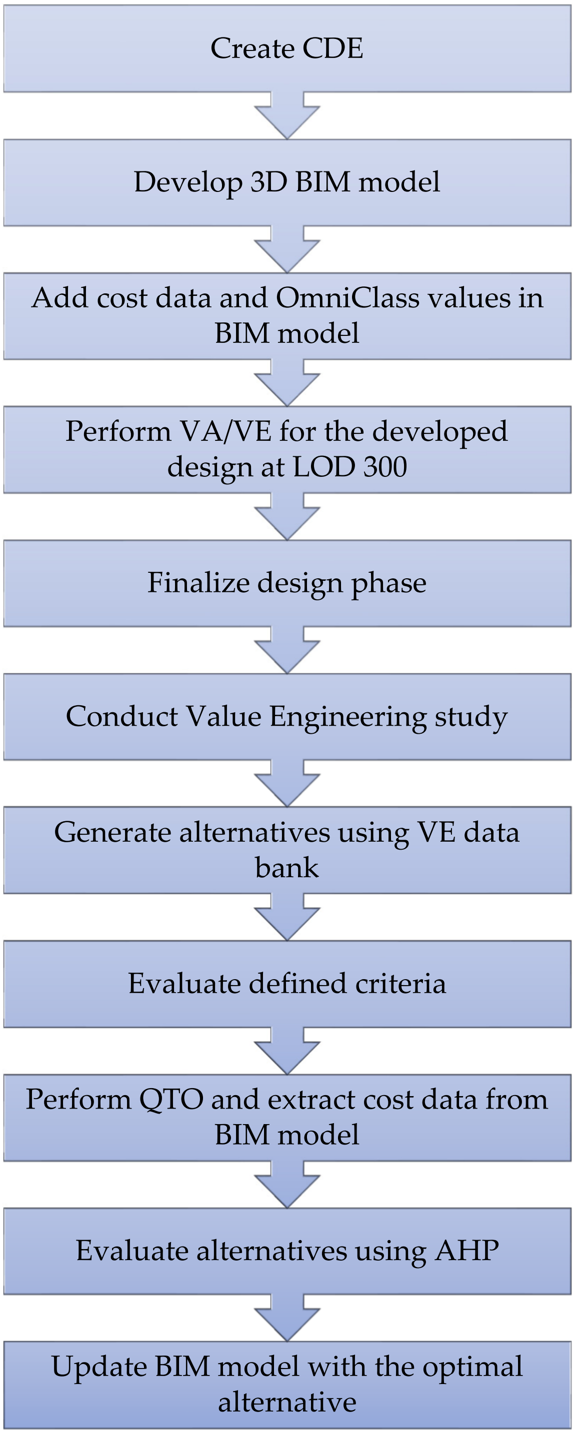

Figure 5. Sequence of framework implementation.

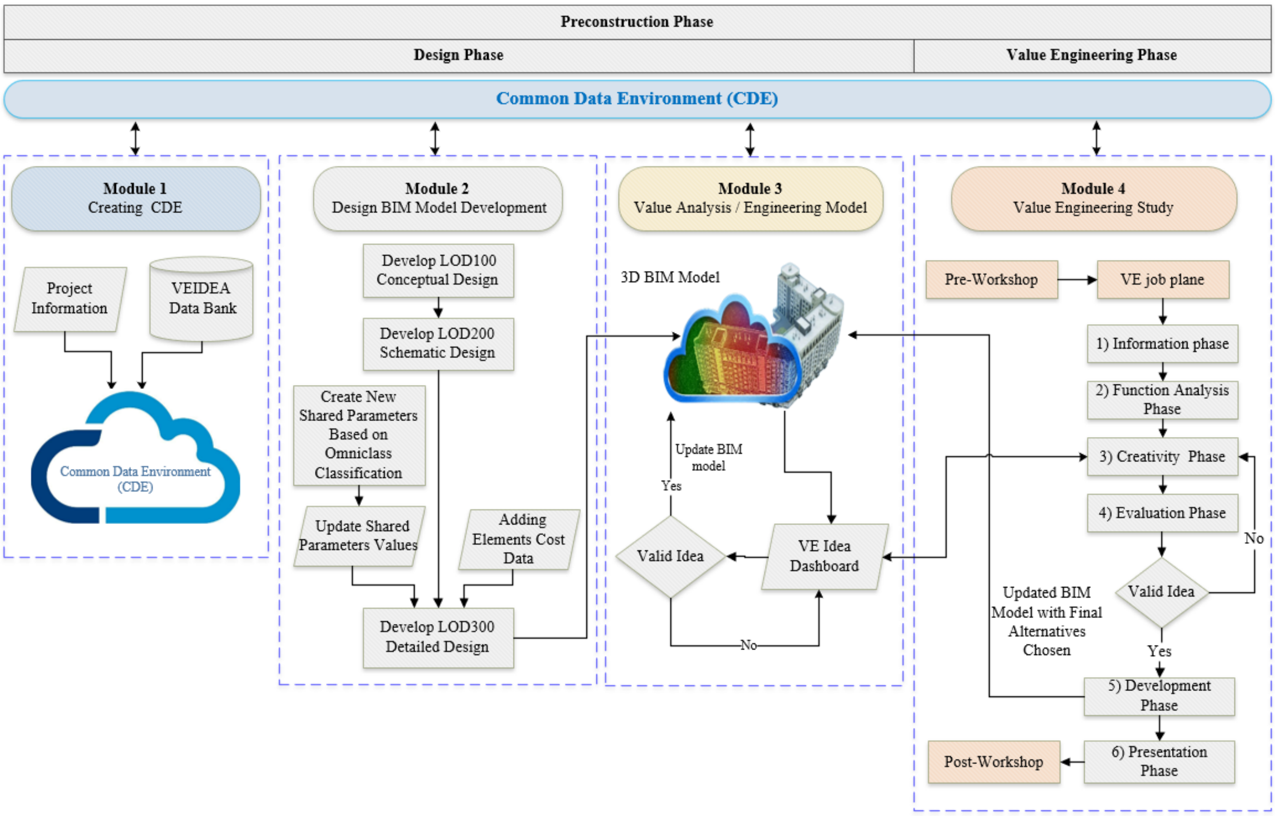

Figure 6. The proposed framework flowchart.

The goal is to select the most appropriate alternative by considering multi-attribute criteria that satisfy the owner requirements and project objectives. Each module has a dedicated subsection that explains its functions in detail.

7.1. Module 1: Creating the CDE

Module 1's framework is illustrated in Figure 7. It begins with establishing a Common Data Environment (CDE) and uploading all the documents relevant to the project. The CDE functions as a single source of truth for all project information, offering secure document storage and digitalized repositories for all documents relevant to the project, including PDFs, spreadsheets, and AutoCAD Drawing (dwg) files. This centralized repository facilitates accessible and organized project information for all participants. The following is a list of project information essential for VE studies.

- Contract documents.
- Project scope and specifications.
- Site plans and surveys.
- Geotechnical reports.
- Cost estimates and budgets.
- Expected project schedule and critical milestones.

In contrast, the VE Idea data bank (VEIDEA) is designed to store and manage VE ideas. The VEIDEA can be created by combining traditional/existing VE ideas with OmniClass classification. The data bank will include general and detailed information about VE ideas. VEIDEA consists of two sections of VE idea information: general and detailed.

- General information includes the idea number, idea contents, date, VE study areas, and the advantages and disadvantages of each idea.
- The detailed information consists of OmniClass classification values related to each idea classified by Elements, Space by Function, Work Results, and Materials.

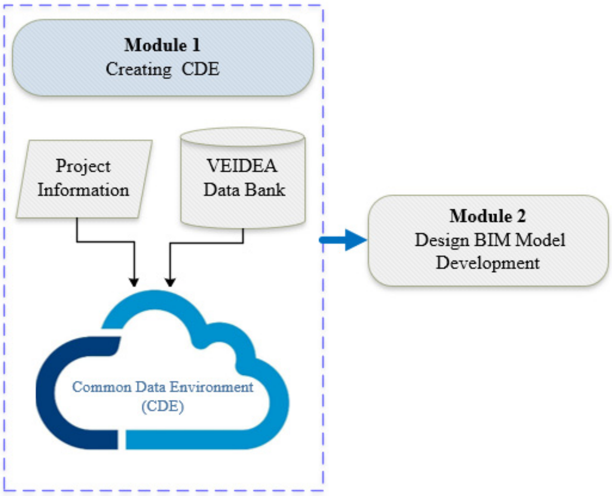

Figure 7. Module (1) framework.

All project information and documents, along with VEIDEA, are stored in the CDE for easy access by all project parties. The proposed system enables users to input detailed search parameters based on the OmniClass classification system, in accordance with BIM objects. Through this functionality, VE teams can conduct targeted searches and retrieve past design ideas relevant to the specific parameters of the project under consideration. This process would substantially reduce the time and effort required to sort past design ideas compared with existing systems. Figure 8 illustrates the process of creating the VEIDEA.

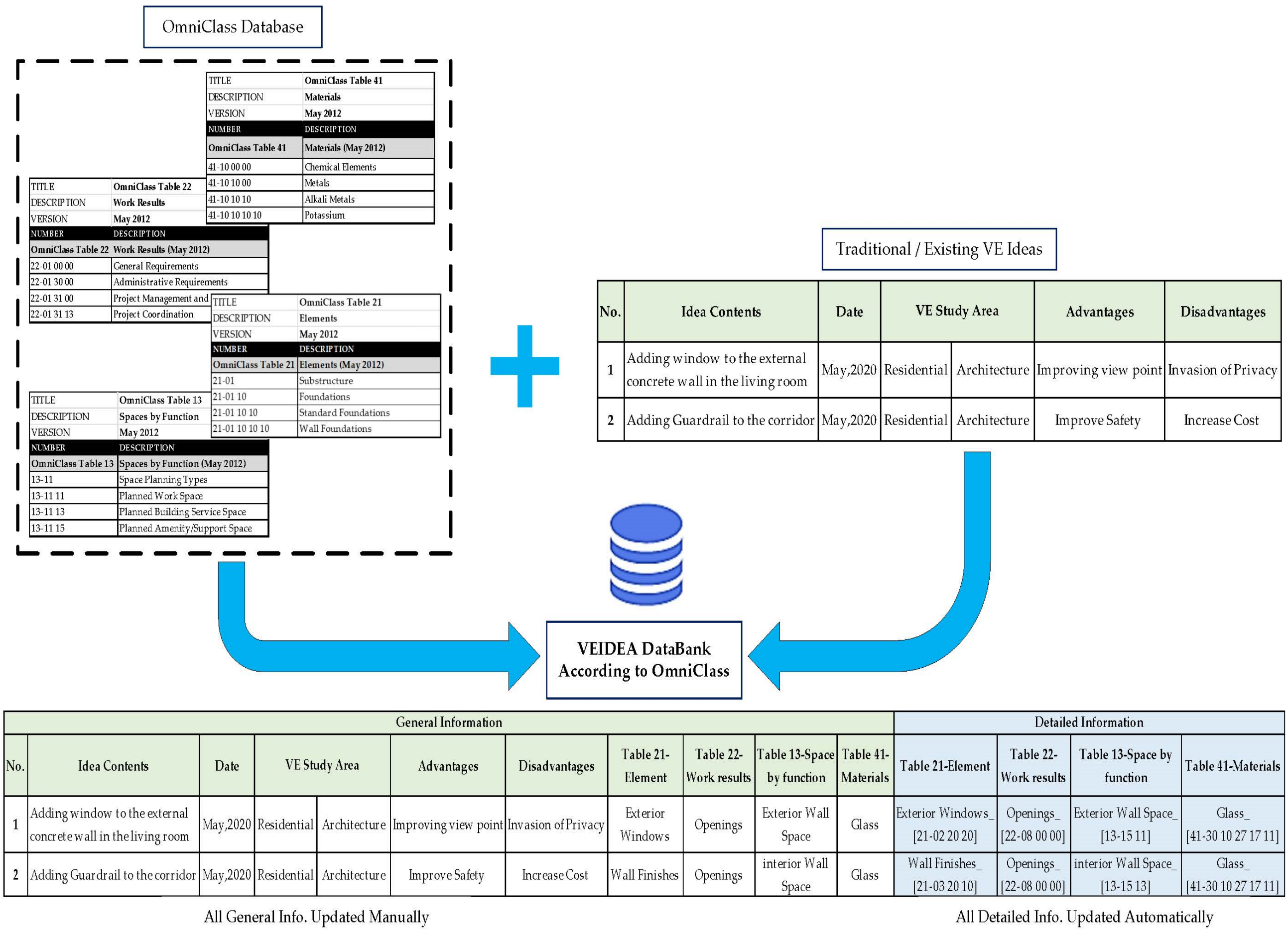

Figure 8. Process of creating VEIDEA data bank.

7.2. Module 2: Design BIM Model Development

Three-dimensional BIM models allow users to visualize objects and structures in a three-dimensional format. This representation enhances the users' comprehension of the project and minimizes the chances of misrepresenting elements. The 3D views enable the VE team to preview the project before construction. This will assist the VE team members in generating a significant number of innovative ideas. In the second module (Figure 9), the 3D BIM model progresses through different levels of development, starting with LOD 100 (Conceptual Design), advancing to LOD 200 (Schematic Design), and finally reaching LOD 300 (Detailed Design). The design team must determine the LOD required [33]. Once the model reaches LOD 300, it should contain the following:

- Detailed 3D modeling of building components.
- Accurate placement and sizing of components.
- Coordination between trades (Architecture, Structural, and MEP).
- Complete clash detection and resolution.
- Construction sequencing.

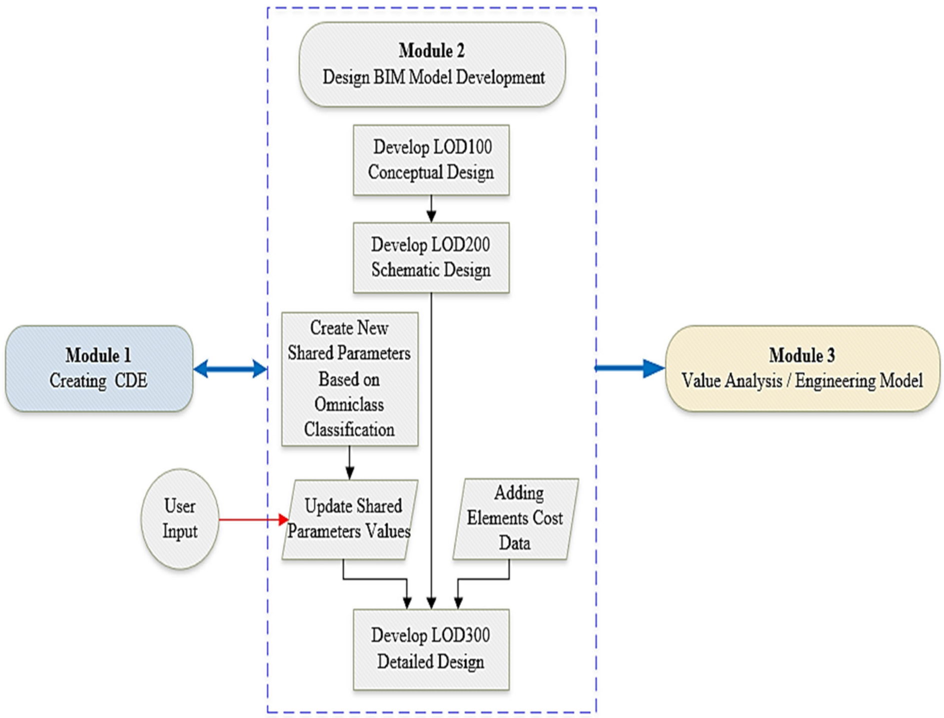

Figure 9. Module (2) framework.

Revit 2025 software provides OmniClass classification only for Table 23 (products in its system), and it is necessary to categorize the predefined OmniClass, which can integrate the BIM model with the VEIDEA data bank as specific parameters into BIM objects—creating new shared parameters that include four new parameters (Table 13—Space by Function, Table 21—Elements, Table 22—Work Results, and Table 41—Materials), as illustrated in Figure 10. This process produces a text file containing the four new parameters of data that can be shared between multiple BIM models and projects.

Upon completion of the process, the new parameter and its associated values can be integrated into the BIM model as a shared parameter by editing the corresponding Revit families. Revit families constitute the core of the internal data structure of the Revit model. Every parametric object is part of a family. Families are classified into two types: (1) System Families and (2) Component Families. Only Component Families can be created, customized, and stored in an external library to facilitate exchange and sharing across different projects or teams.

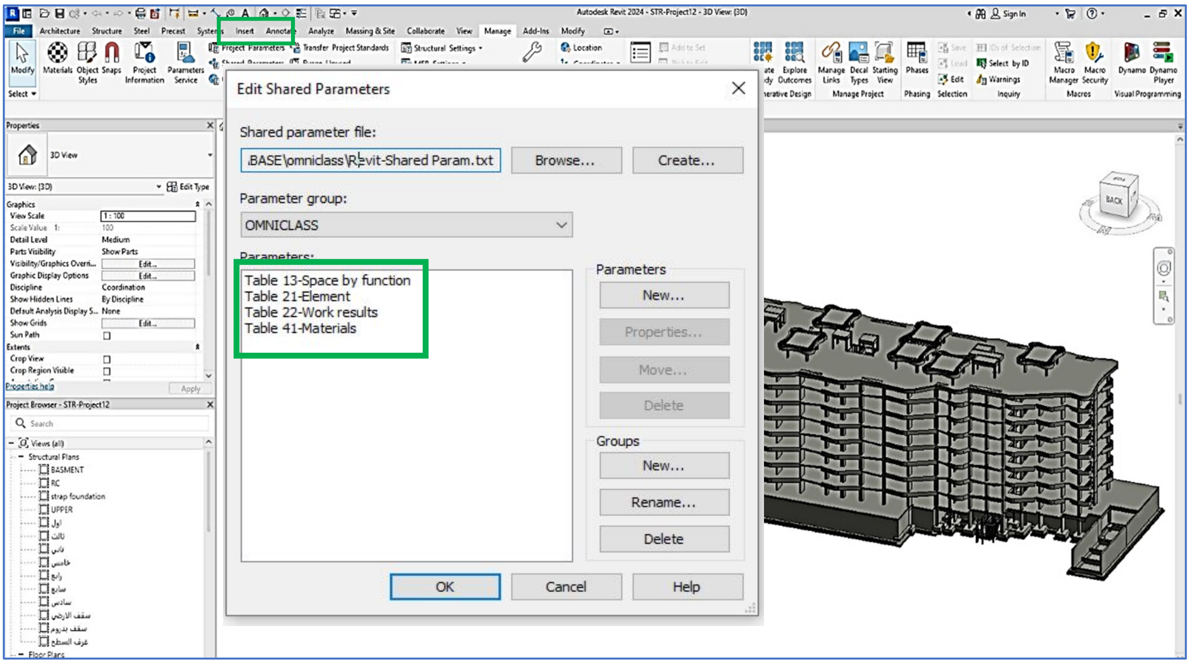

Figure 10. The newly added shared parameter.

Using "Family Editor", the new parameter could be added to the BIM objects. An example of a concrete column family is presented in Figure 11 to illustrate the addition of the four new parameters and their related values according to OmniClass classification. OmniClass classification values were manually assigned to each of the BIM objects through their families. After importing the modified family into our BIM model, new parameters and their related values were assigned to their elements. Figure 12 presents a concrete column property after including the new parameters in the BIM model, which can be used later in the VE process.

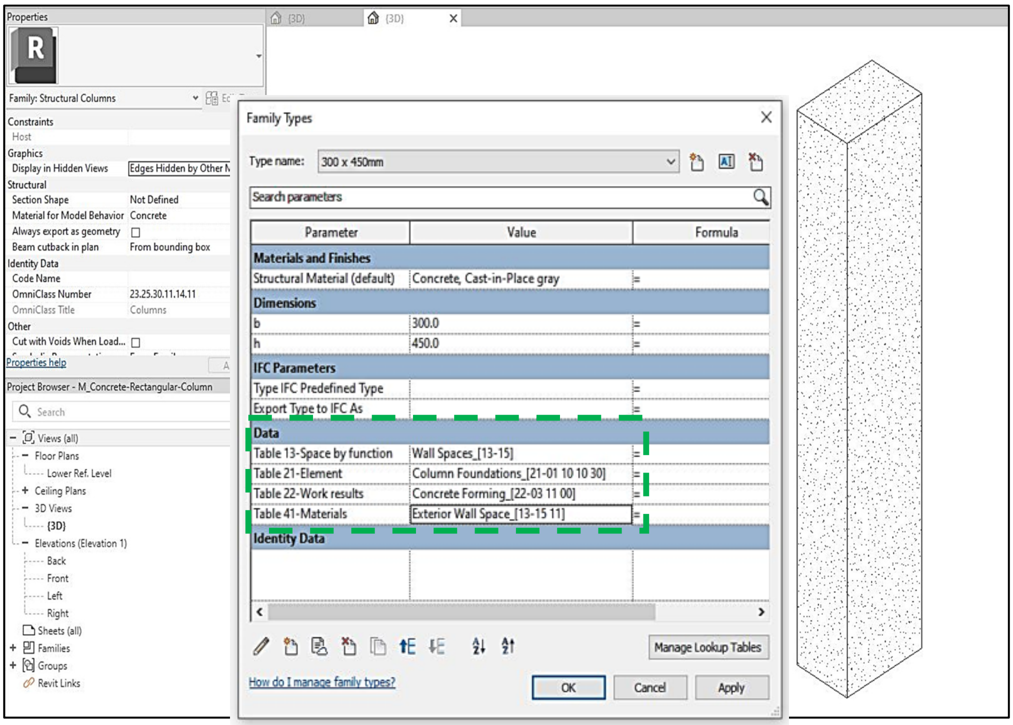

Figure 11. Creating specific parameters based on OmniClass.

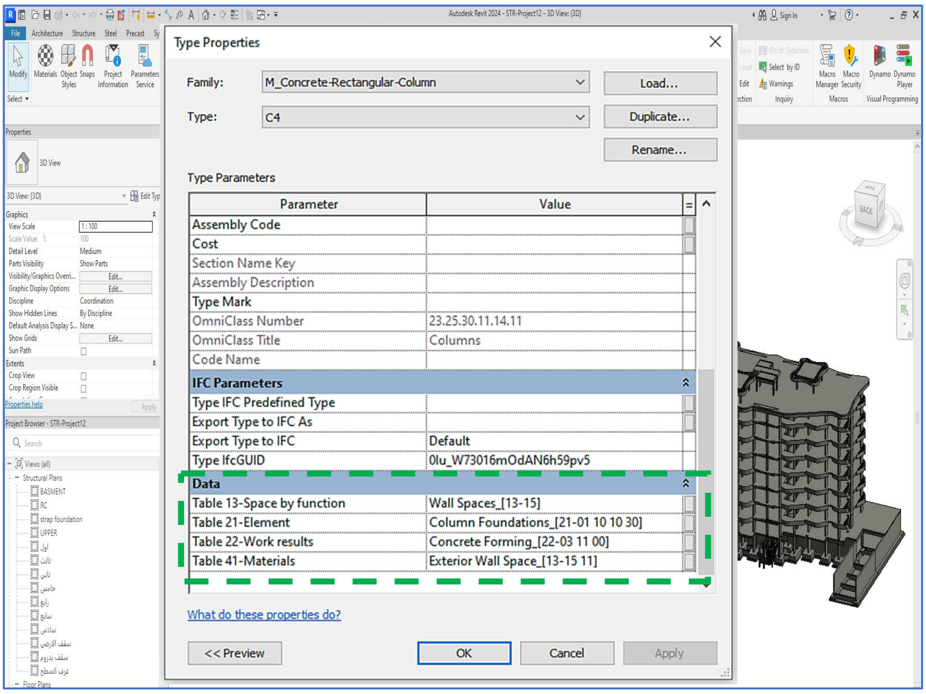

Figure 12. Concrete column property after including new parameters.

Capitalizing on the benefits of OmniClass values previously incorporated into the model, the final step in this module entails integrating cost data into the BIM model for all elements. This process is facilitated by establishing a connection between the cost database and the CSI MasterFormat values incorporated in each model element, as mentioned in the literature review. Table 22—Work Results represents the MasterFormat classification that categorizes the work results in the form of numbers and titles [34].

To streamline this process, all components of the BIM model were extracted and exported as MS Excel files. This file contains the element ID, all OmniClass parameter values, and cost data, which were initially left blank. Subsequently, the exported Excel file was linked with the cost database developed based on the CSI MasterFormat (Figure 13). Finally, the cost data were incorporated into an exported Excel file and reimported into the 3D model (Figure 14). The process of extracting the data from the Revit model and importing the modified data to it again is automated using the "Import" and "Export" add-in functionalities integrated into the BIM model, as illustrated in Figure 15.

OmniClass Table 22 Number	Work Results Description	MasterFormat	Unit Rate/LE	Unit
22-03 20 00	Concrete Reinforcing	03 20 00	1200	m^3
22-03 21 00	Reinforcement Bars	03 21 00	42000	Ton
22-03 23 00	Stressed Tendon Reinforcing	03 23 00	75000	Ton

Figure 13. Cost database based on CSI MasterFormat Unit Rate/EGP".

The process of adding cost data to the 3D BIM model increases the dimensionality of the model to the fourth dimension (4D). Four-dimensional (4D) modeling offers significant advantages during the design phase, enabling visualization and automatic cost calculations for the alternatives under consideration. BIM models provide precise quantity takeoffs and component schedules at each project design stage. Consequently, the cost estimate for each alternative can be calculated. Accordingly, the virtual environment (VE) team will gain a comprehensive understanding of the outcomes of their proposed modifications.

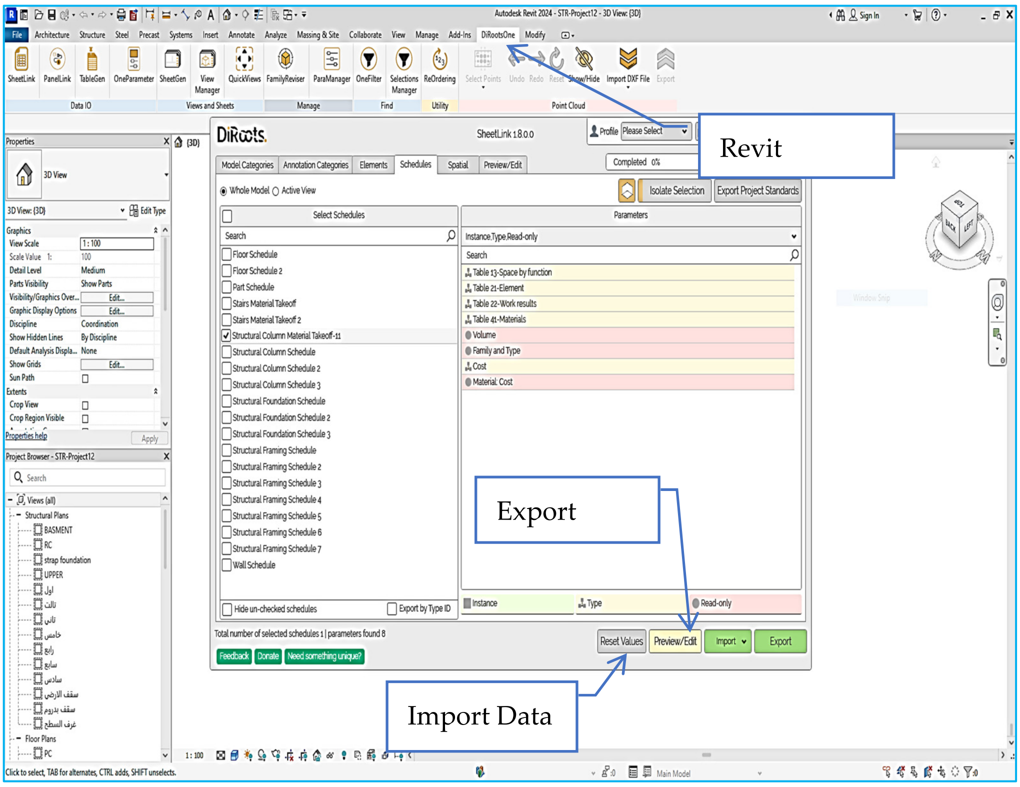

Figure 14. Revit add-in for exporting and importing model schedule.

Figure 15. The process of including the cost data in the BIM model.

Upon completion of Module (2), the primary deliverable will be a comprehensive design BIM model enriched with the cost data and OmniClass parameter values, as presented in Figure 16.

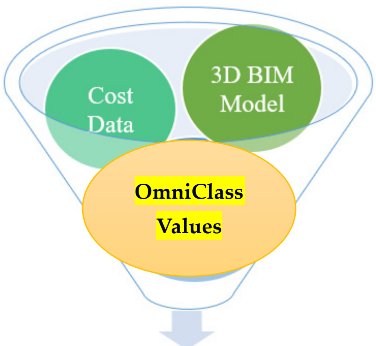

Figure 16. The output from Module (2).

7.3. Module 3: Value Analysis/Engineering Model

Module (3) depends mainly on the design of the BIM generated by Module (2), as illustrated in Figure 17. During the design development phase, the established VEIDEA data bank was linked to the BIM model, which contains pre-assigned OmniClass parameter values for all elements. This enabled a facilitated search for past VE ideas stored in the VEIDEA data bank related to any specific object within the BIM model. To refine the search criteria for retrieving relevant VE ideas, various search parameters, including Elements, Space by Function, Work Results, and Materials, must be utilized. After reviewing the ideas, the selected idea was implemented by directly modifying the BIM model. This module allows the design team to systematically integrate past VE ideas into the ongoing design development process. Consequently, this proactive approach potentially reduces the need for extensive design changes that may occur after design completion. Additionally, this approach helps comprehend the designs through 3D visualization and enhances the effectiveness of VE implementation.

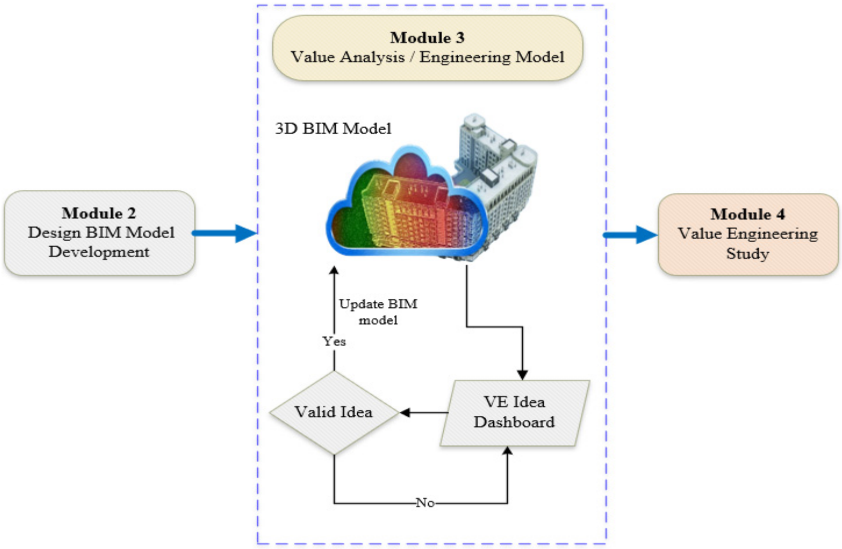

Figure 17. Module (3) framework.

An add-in was developed and installed in the BIM to facilitate the implementation of this module. The VE–BIM integration add-in's objective is to facilitate design enhancement by utilizing the VEIDEA data bank. The dashboard interface is displayed upon selecting the VE–BIM integration add-in (1 in Figure 18). Four OmniClass search parameters can be selected on the left to adjust the classification level to retrieve relevant VE ideas (2 in Figure 18). In our case, "Element" and "Space by Function" are selected, with their corresponding descriptions assigned as "Floor Decks, Slabs, and Toppings" and "Office Spaces", respectively, as illustrated in 3 in Figure 18. Subsequently, VE ideas are filtered according to previously assigned search parameters. The resulting VE idealist comprises concepts related to modifying the reinforced concrete (RC) slab type and its associated advantages and disadvantages (4 in Figure 18). The user/designer may accept the preferred ideas and reject others at this stage. This process significantly reduces time expenditure during the VE workshop, as the VE team can exclude previously reviewed and decided ideas from further consideration.

This module serves as an essential tool for the design team, facilitating a comprehensive review of previous Value Engineering ideas and incorporating them into the design development phase. This module enables a proactive approach to design optimization. This systematic incorporation of VE principles early in the design process leads to the following conclusions:

- Reduce the risk of design modifications in later stages.
- Reduce iteration cycles.
- Enhance the design process.
- Improve the final design's value.

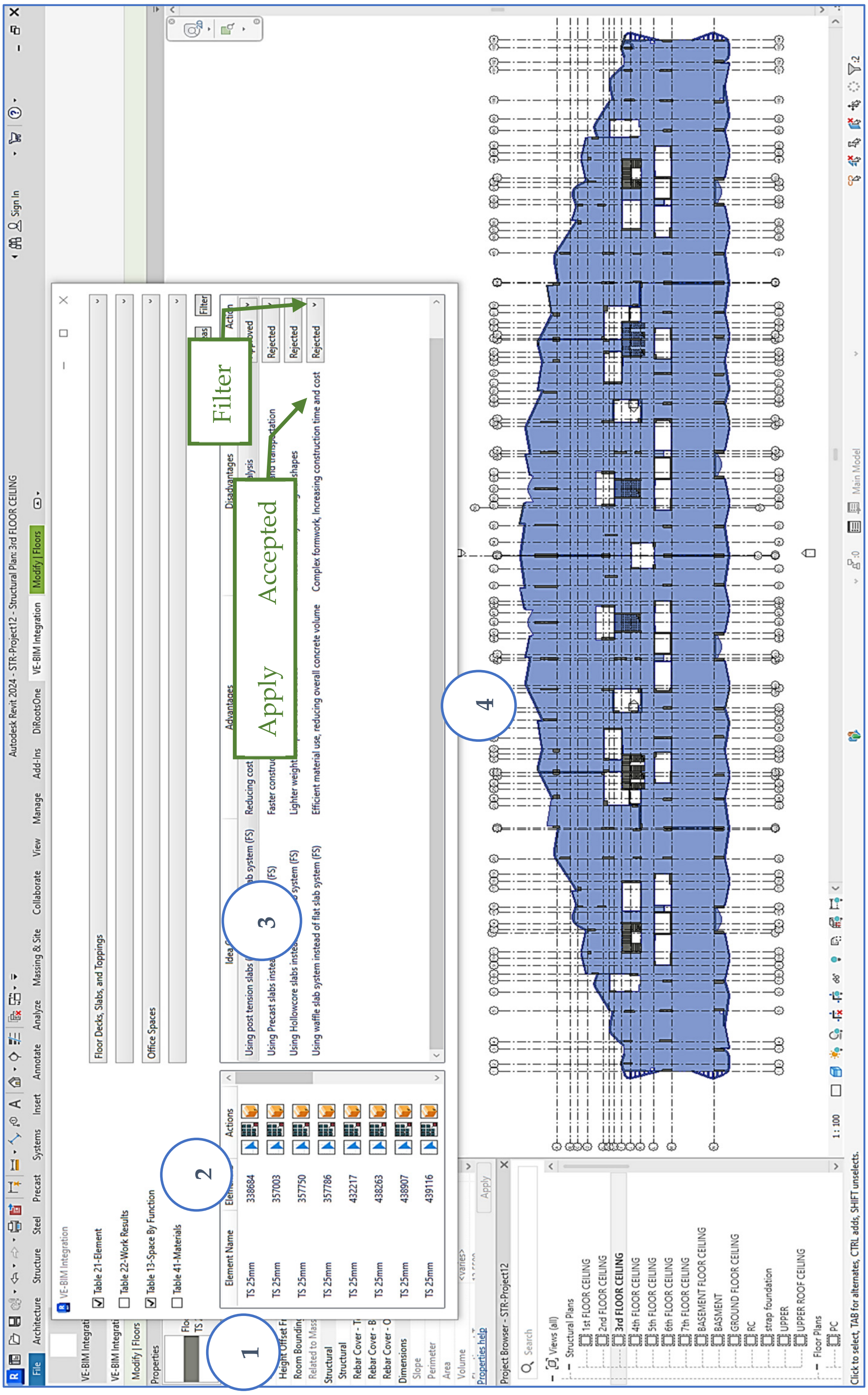

Figure 18. The VE–BIM integration add-in dashboard.

7.4. Module 4: Value Engineering Study

The implementation of Value Engineering relies on the VE team's collective expertise and innovative thinking. The purpose of the proposed methodology is not to remove human creativity, but the main objective is to facilitate the execution of the Value Engineering study, which will save time and effort. The objectives of this study are as follows:

- Assist the user in going through the Value Engineering job plan systematically.
- Reducing the amount of paperwork during the Value Engineering study as the model carries out all the calculations, such as quantity takeoff, cost calculation, and evaluation.
- Reduce the timing and execution of the VE workshop studies.
- Saving the data in an organized way makes it easy to retrieve any information.

The VEIDEA data bank will contain the previous ideas and the new ones generated during the study, which will be available for the user to retrieve at any time. The Value Engineering process is implemented by following a particular job plan. Following the phases of the Value Engineering study in their order is very important because they are based on each other according to this sequence, as illustrated in Figure 19.

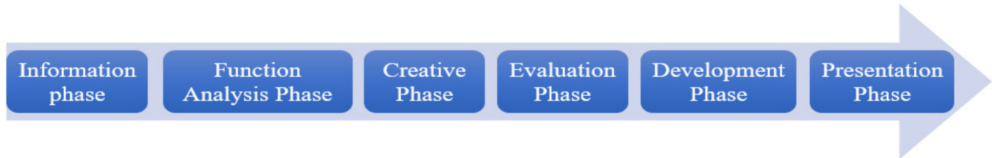

Figure 19. Value Engineering job plan phases.

The VE process commenced with the formation of the VE team. The first step in the Value Engineering job plan is the information gathering phase. The aim is to collect all relevant project information. To facilitate this task, the CDE emerges as a single platform for streamlining document management across the project lifecycle. The CDE contains all the project information and grants the VE team secure and global access to the project information through cloud-based storage facilitated by appropriate permissions. The function analysis phase begins by using the Functional Analysis System Technique (FAST) to define the project scope and clarify the essential functions that must be maintained. Ideas are then generated, and the best ones are selected for further development.

A limitation of the proposed framework is its inability to directly consider the effect of structural design modifications on the other elements of the building under study. Specifically, changes to the primary structural elements, such as the slab type, may require adjustments to the secondary elements, such as the column and foundation dimensions, along with their reinforcement values. While the framework optimizes the primary structure, these secondary element modifications must be redesigned and modified by the designer.

7.5. Criteria Assessment and Automated Evaluation of Alternatives

The proposed framework introduces an integrated model to facilitate value-driven decision making among generated alternatives for owners, professional designers, and VE team members. The AHP is employed as a tool for multiple-criteria decision making (MCDM). The AHP technique was implemented in two stages. Initially, the criteria were evaluated against one another to determine their relative weights. Subsequently, the alternatives were evaluated against each criterion to generate a score for each alternative. The weighting of the criteria was defined based on user preferences. The evaluation phase of alternatives is implemented by comparing the criteria, comparing the alternatives versus each criterion, and designing to help stakeholders choose the best design alternative. Criteria weights are determined by the pairwise comparison matrix of the relative importance of the criteria [35]. Therefore, some criteria are not measurable, and the criteria weights are estimated based on the importance of the criteria in the design process. The model was developed using the AHP as a dynamic decision making tool and the choice of appropriate decision for design alternatives. According to the information and drawings created in the BIM model, the model provides multi-standard decision making solutions, as follows:

- Choose the appropriate design alternative from a possible set of alternatives.
- Classification and prioritization of alternatives in accordance with the criteria.
- Describes the impact of specific criteria on performance alternatives.

Figure 20 illustrates the evaluation process using the AHP.

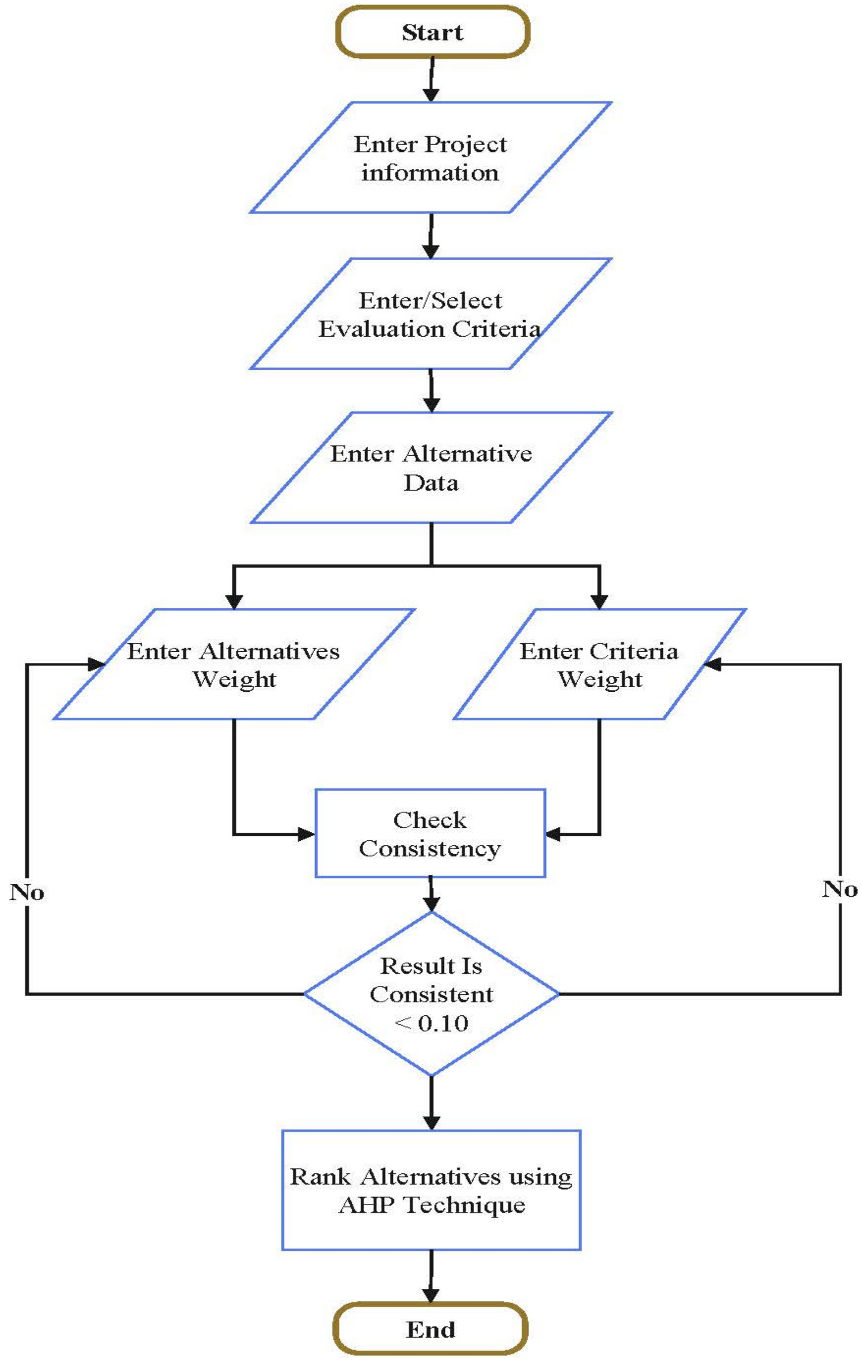

Figure 20. Alternative evaluation procedures using the AHP technique.

The goal of the framework is to select the most appropriate alternative by considering multi-attributed criteria that satisfy owner requirements and project objectives by leveraging the benefits of BIM and a CDE. Finally, Figure 21 shows the tools used to enhance the Value Engineering process.

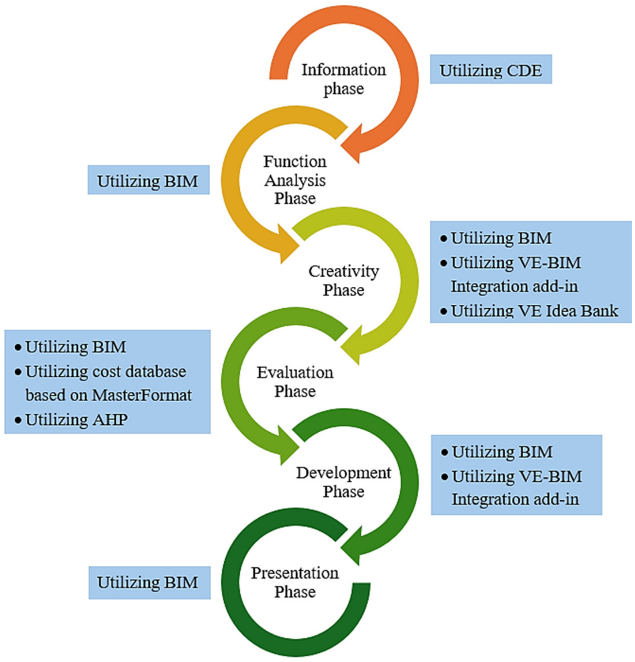

Figure 21. Value Engineering phases and the tools used to enhance each phase.

8. Case Study Application

This section presents a practical application of the proposed framework through a comprehensive case study to illustrate its features and capabilities. The process begins in the pre-construction phase at the beginning of the design phase. The case study focuses on an office building project with the objective of finding the most suitable alternative for the building by trying different structural and architectural designs through an evaluation process.

The building comprises nine floors (basement, ground, and seven typical floors), as illustrated in Figure 22. The project information is as follows:

- The project is located in the new administrative capital, Cairo, Egypt.
- The footprint area is 5371 m^2.
- The total built-up area is 37,358 m^2.
- The construction works start in 2022.
- The project's duration is 22 months.
- The contract price is EGP 147 million (about USD 6 million).
- The structural system of the building was cast in situ using reinforced concrete flat slabs.
- The foundation system has isolated footings.

Figure 22. Three-dimensional perspective for the project.

8.1. Creating CDE and Design BIM Model Development

Autodesk Construction Cloud was selected as the CDE. Figure 23 shows all the project documents uploaded to the CDE. All project disciplines, such as structural, architectural, and MEP design teams, have access to the CDE. In addition, the VE–BIM integration add-in software, including the VEIDEA data bank as an Excel file, will be uploaded to the CDE.

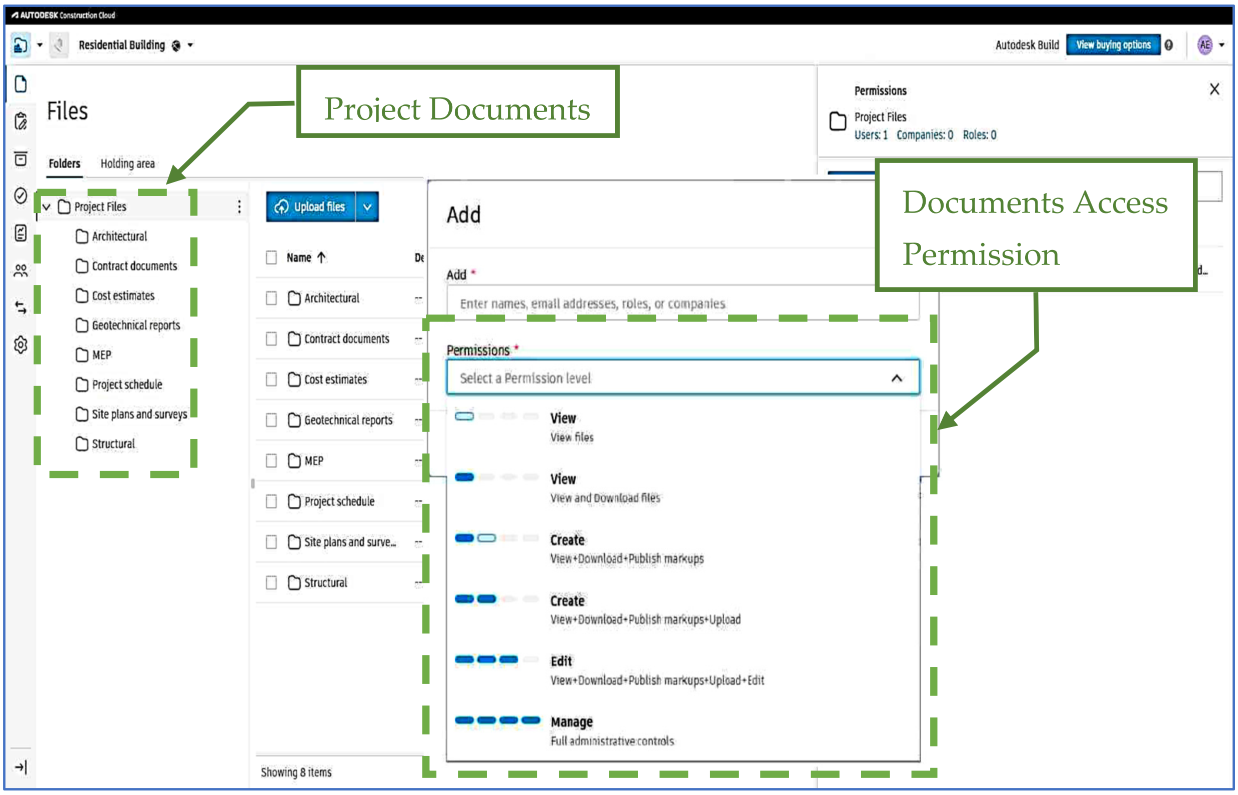

Figure 23. Project documents and access permission on a CDE.

During the design phase, all the design teams used the BIM environment and its tools. Revit 2024 was used to create the building's 3D model (architectural and structural) until an LOD of 300 was reached. Figures 24 and 25 illustrate the architectural and structural 3D models of the project, respectively.

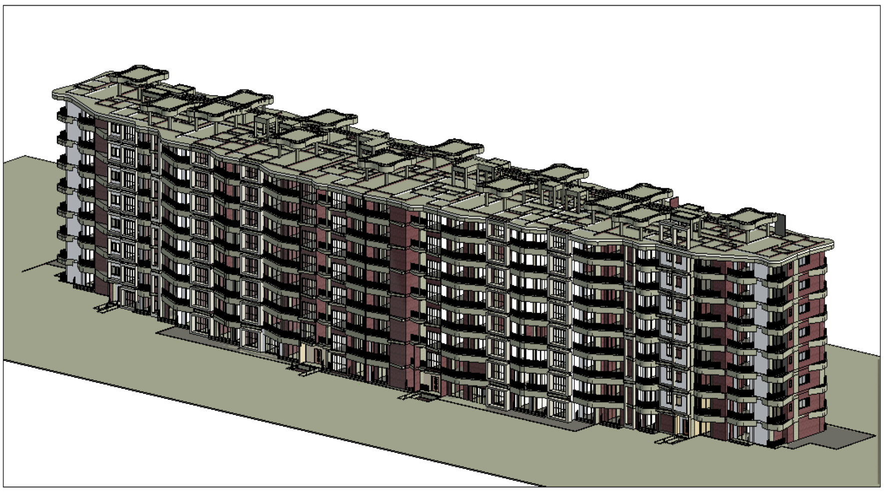

Figure 24. A 3D architectural BIM model of the project (LOD 300).

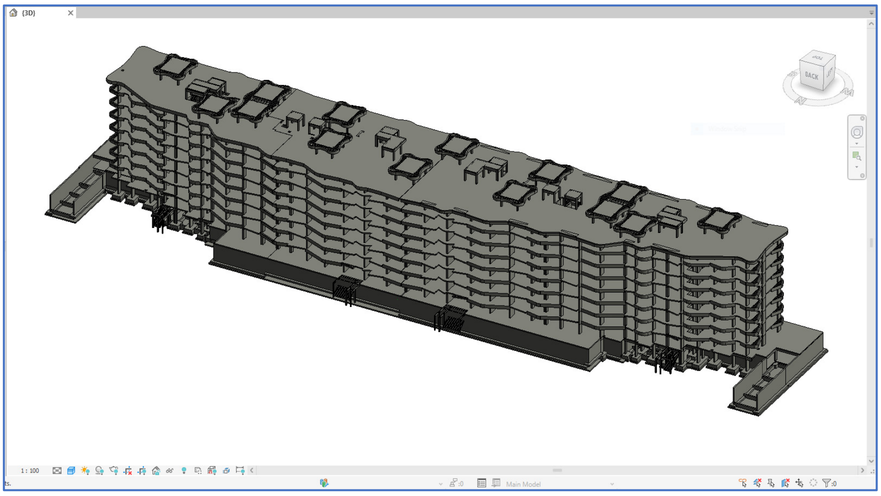

Figure 25. A 3D structural BIM model of the project (LOD 300).

After finishing the 3D design model, the four new shared parameters related to the OmniClass classification (Table 13—Space by Function, Table 21—Elements, Table 22—Work Results, and Table 41—Materials) were inserted into the BIM model, and their related values according to the OmniClass classification were added manually by the user for all the elements in the model. After incorporating OmniClass values, the cast data were imported into the BIM model. Finally, the VE–BIM integration add-in software was installed in the BIM model, as shown in Figure 26.

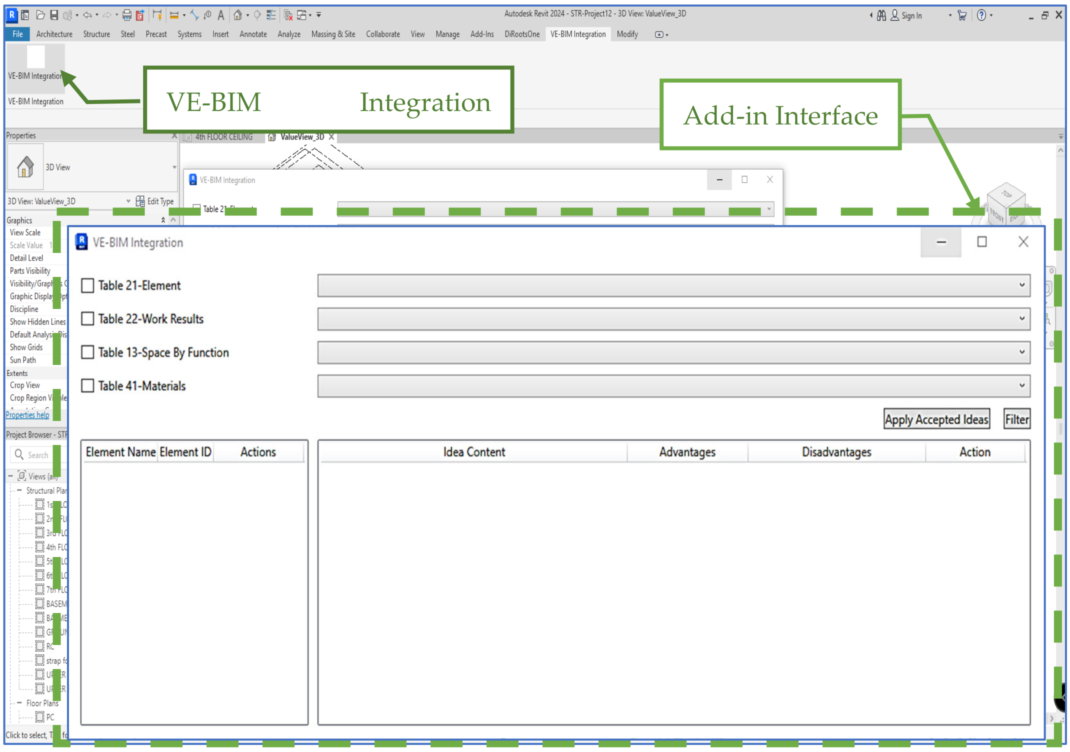

Figure 26. VE–BIM integration add-in interface.

8.2. Value Analysis/Engineering Model

Table 2 presents a summary of the search results after using the add-in and applying the search parameters, as illustrated in Section 7.3. At this stage, the user/designer may accept the preferred ideas and reject others. The project is primarily a conventional office building with spans ranging from 5 to 8 m. Consequently, the implementation of post-tensioned

(PT) slabs instead of a flat slab (FS) system is highly recommended. The user/designer can virtually select the required slab element to implement the chosen VE idea (PT slab) and modify the BIM model by selecting "Apply accepted idea".

Table 2. The search results of past VE ideas.

Idea Contents	VE Study Area	Advantages	Disadvantages	Action
Using post-tension slabs (PT) instead of flat slab system (FS)	Structural	Reducing cost by using less concrete and reinforcement	Requires detailed structural analysis	Accepted
Using precast slabs instead of flat slab system (FS)	Structural	Faster construction time	Higher initial costs for molds and transportation	Rejected
Using hollow core slabs instead of flat slab system (FS)	Structural	Lighter weight compared to solid slabs	Limited flexibility for irregular shapes	Rejected
Using a waffle slab system instead of a flat slab system (FS)	Structural	Efficient material use, reducing overall concrete volume	Complex formwork, increasing construction time and cost	Rejected

The original design is a flat slab (FS) with 250 mm thickness. The estimated slab cost is approximately EGP 5,874,000 (USD 239,755). The second alternative is a post-tension slab (PT slab) with a slab thickness of 220 mm. The estimated slab cost is approximately EGP 4,724,400 (USD 192,832). The cost calculation for each system is presented in Table 3.

Table 3. Typical floor slab results and comparison.

	Flat Slab	PT. Slab
Slab thickness (ts mm)	25	22
Slab area (m^2)	3760	3760
Concrete volume (m^3)	940	827
Concrete unit cost (EGP/m^3)	1200	1200
Reinforcement weight (ton)	113	62
Reinforcement rate (Kg/m^3)	120	75
Tendon rate (Kg/m^2)	—	4
Reinforcement unit cost (EGP/ton)	42,000	42,000
Tendon unit cost (EGP/m^2)	—	75
Total cost	5,874,000	4,724,400
Cost difference (EGP)	1,149,600	
Saving percentage %	20%	

The modification of the slab type/system necessitates a comprehensive reassessment of the entire structural framework. As the slab thickness is reduced, the designer must consider these modifications and redesign both the foundation and vertical elements. This optimization process ensures structural integrity and efficiency and maximizes the benefits of the initial Value Engineering decision.

8.3. Value Engineering Study

A Value Engineering study will be conducted according to the standardized procedures established by SAVE International. Furthermore, this study will be enhanced by exploiting the advantages afforded by BIM technology and the implementation of the CDE. This integrated approach aims to streamline the Value Engineering process. The process begins when the VE team starts gathering data and decides to generate innovative ideas aligned with the project objectives.

8.3.1. Pre-Workshop Phase

The focus of the pre-workshop phase is to establish a clear communication line between the project manager and designer to acquire all the necessary information related to the project and select a VE team with experience related to the project scope of work. The project is described in detail in Section 8.

8.3.2. VE Job Plan (Workshop Stage)

The workshop phase involves a structured job plan to identify opportunities to improve a project's value while ensuring compliance with project objectives and adherence to project constraints. The VE job plan consists of the following six systematic steps.

8.3.3. Information Phase

At this stage, all project information and specifications are provided to the VE team through access to the CDE cloud (Figure 23). This centralized repository facilitates seamless collaboration and ensures that the team has ready access to all project data, where it can comprehensively review the project data, drawings, and specifications to gain a thorough understanding of the project's purpose and objectives. The following information is provided:

- Project contract documents.
- Design BIM models and project drawings (architectural and structural drawings).
- Project specifications.
- Bill of quantities.
- Project cost.
- Project schedule.
- Soil investigation report.

8.3.4. Function Analysis Phase

The Function Analysis Systems Technique (FAST) diagram graphically illustrates the interrelationships of project functions and is often invaluable in accomplishing this understanding. Figure 27 shows the FAST diagram of the case study.

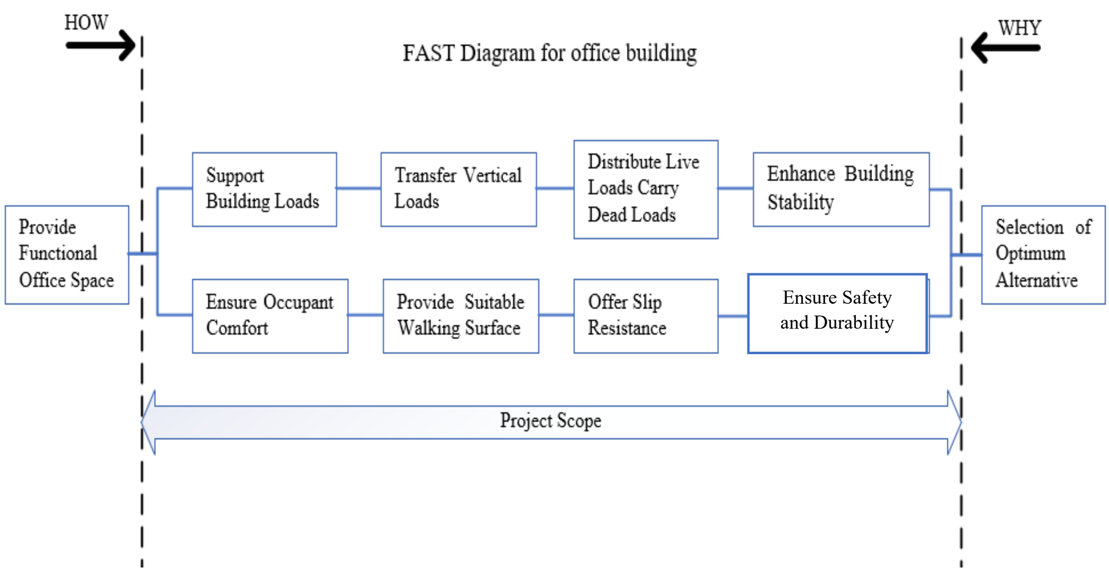

Figure 27. FAST diagram for case study.

8.3.5. Alternatives Generation Using VE–BIM Integration in the Creativity Phase

In this phase, BIM integration serves as a comprehensive repository for all essential information regarding the alternatives. This integration facilitates the development of cost-effective alternatives that fulfill essential functions. The VE team uses the VE–BIM integration add-in to access and search the VEIDEA data bank for relevant VE ideas. "Element", "Work Results", and "Space by Function" are selected, with their corresponding descriptions assigned as "Tile Flooring", "Flooring", and "Office Spaces", respectively. Figure 28 illustrates the parameters and their corresponding descriptions used to search for flooring material ideas. The action for the displayed ideas was assigned as "Pending Evaluation".

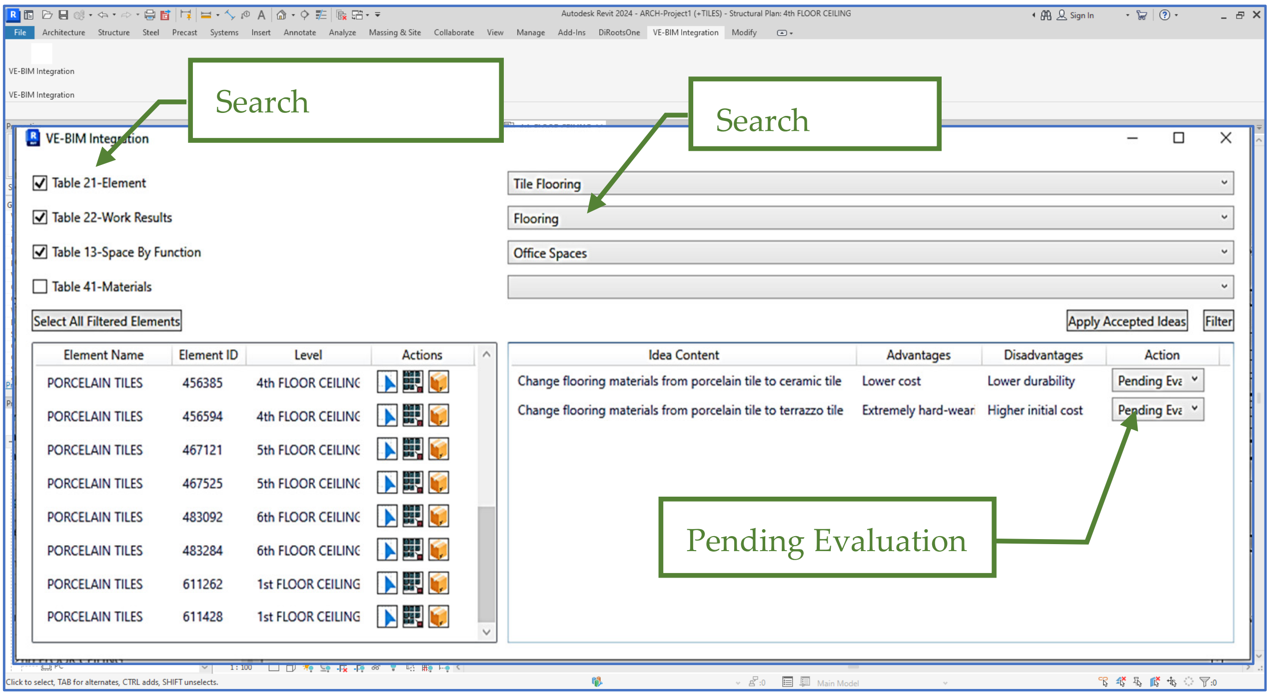

Figure 28. Search results for flooring material ideas.

For each proposed alternative, a distinct BIM model was generated. These alternatives were evaluated in the subsequent phase. In this case, alternatives for changing the flooring material are as follows:

- Porcelain tile (original design).
- Ceramic tile.
- Terrazzo tile.

The action status of ideas reviewed during the Value Analysis/Value Engineering phase was recorded and displayed. If the designer had already made a decision regarding an idea, the decision was stored and appeared in the action field adjacent to the idea.

A key advantage of BIM integration is the ability to perform accurate quantity take-off. The BIM model facilitates the extraction of precise cost data for each alternative, as illustrated in Figure 29.

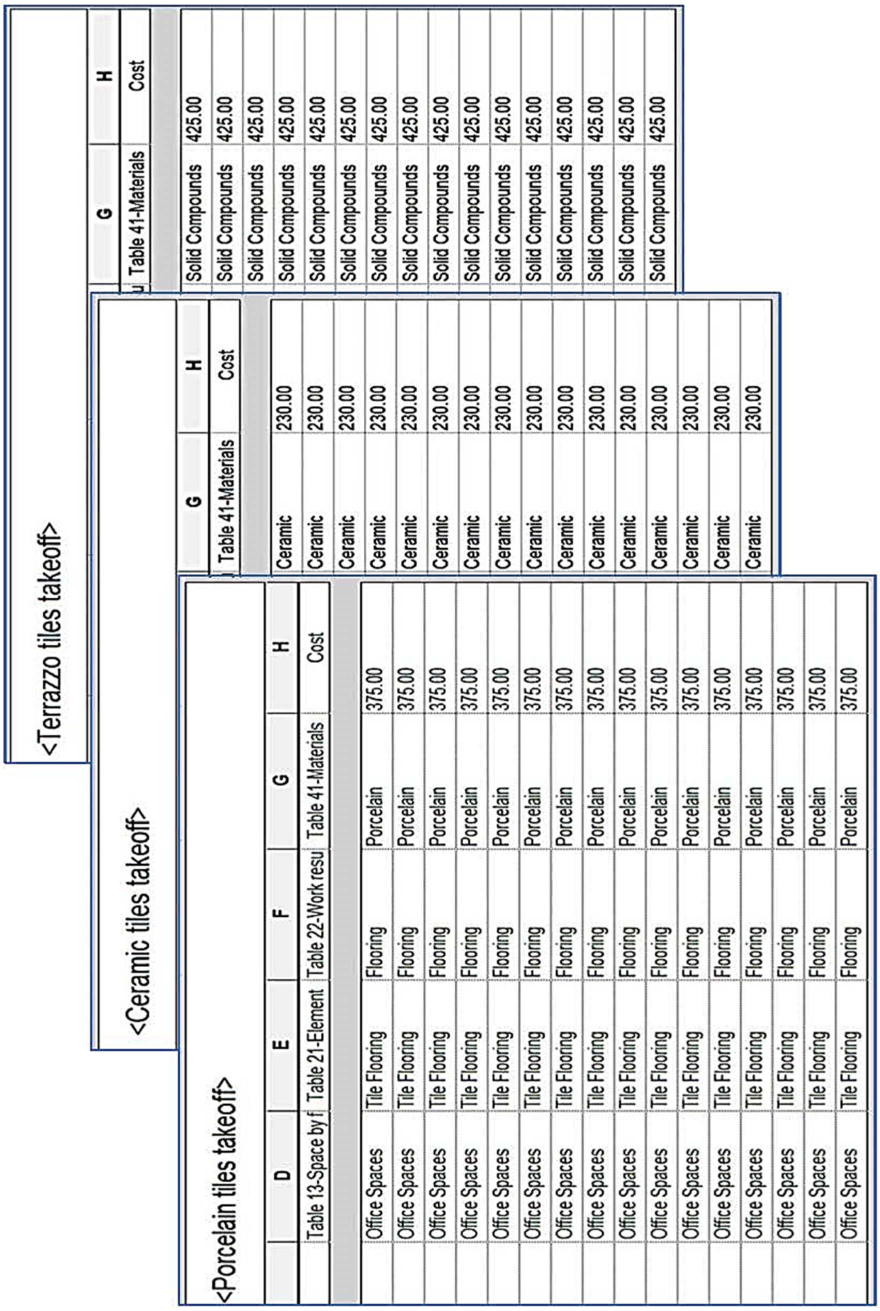

Figure 29. Cost data for each alternative extracted from the BIM model.

8.3.6. Evaluation of Generated Alternatives

The evaluation phase is implemented using AHP, which is designed to help the user identify an alternative suitable for the design and prioritize alternatives based on predefined criteria. The evaluation is implemented by comparing the criteria and alternatives with each criterion to help choose the best alternative.

The user is asked to enter all general project information required for this study, such as the project name, project type, project description, and interest rate. The user is also asked to define/select the evaluation criteria, which is an essential component of the evaluation process. The defined criteria for this case study are Funding Capabilities, Construction Time, Durability, Constructability, Availability of Material, Safety, and Aesthetics, as presented in Figure 30. The user proceeds to the next step by entering the suggested alternatives based on the ideas displayed by the VE–BIM integration add-in used in the previous phase.

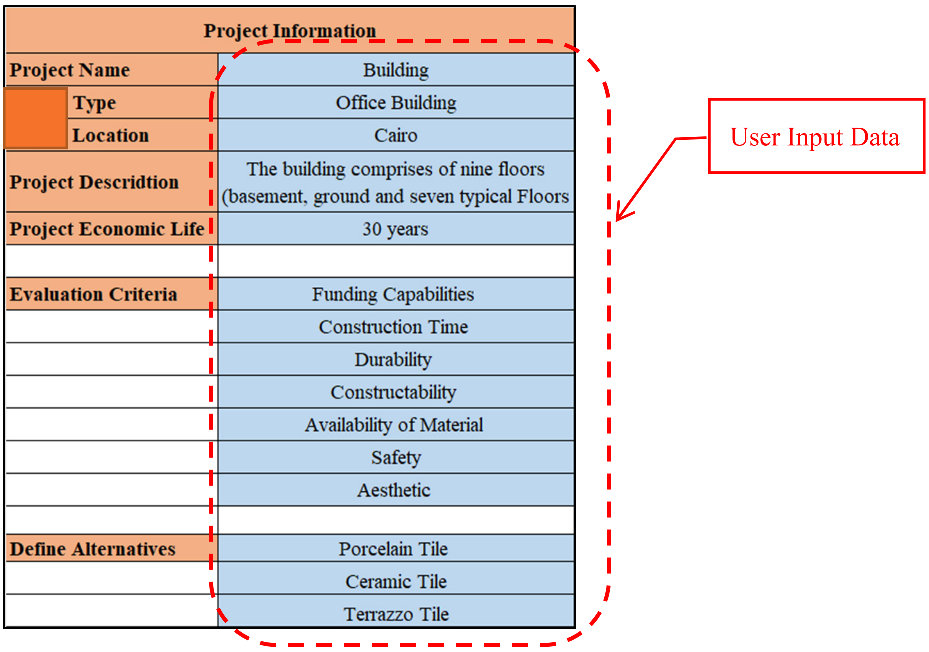

Figure 30. User input data.

The pairwise comparison evaluation was started by establishing the weight of the selection criteria. Criteria weights were determined using a pairwise comparison matrix. Initially, the criteria were compared to each other, and then alternatives were compared against each criterion to generate a score for each alternative, as shown in Figure 31.

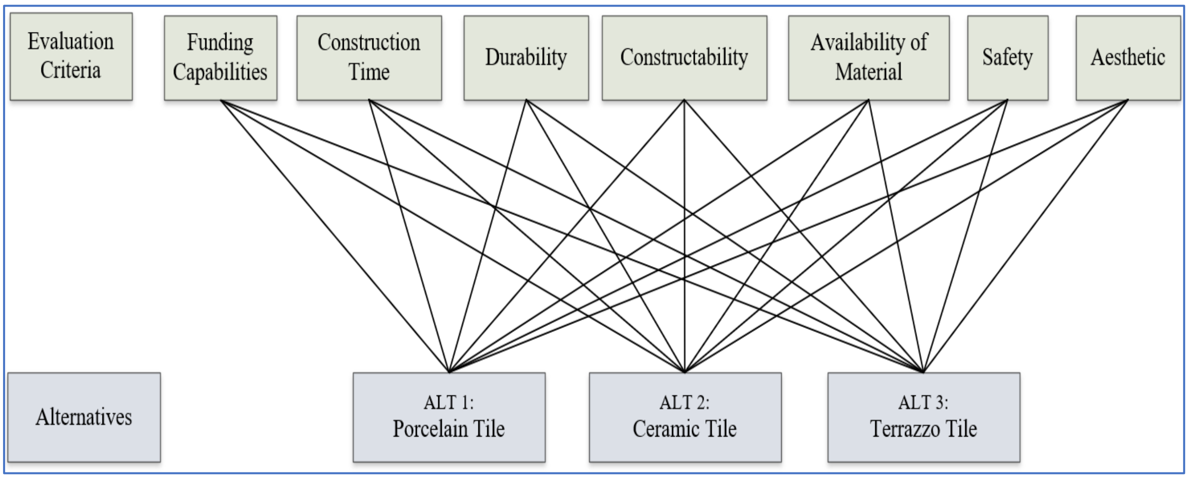

Figure 31. AHP hierarchy diagram for the case study.

The standard 1–9 scale was used in the pairwise comparisons, and the relative scale for measurement is presented in Table 4.

Table 4. Scale of measurement for AHP [36].

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another

Table 4. *Cont.*

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

Figure 32 presents the user-input importance levels for each criterion, and Figure 33 displays the calculated weights derived from these inputs.

	Funding Capabilities	Construction Time	Durability	Constructability	Availability of Material	Safety	Aesthetic
Funding Capabilities	1.00	3.00	2.00	4.00	5.00	2.00	6.00
Construction Time	0.33	1.00	0.50	2.00	3.00	0.33	4.00
Durability	0.50	2.00	1.00	3.00	4.00	0.50	5.00
Constructability	0.25	0.50	0.33	1.00	2.00	0.25	3.00
Availability of Material	0.20	0.33	0.25	0.50	1.00	0.20	7.00
Safety	0.50	3.00	2.00	4.00	5.00	1.00	5.00
Aesthetic	0.17	0.25	0.20	0.33	0.14	0.20	1.00

Figure 32. Criteria pairwise comparison matrix.

	Funding Capabilities	Construction Time	Durability	Constructability	Availability of Material	Safety	Aesthetic	**Criteria Weight**
Funding Capabilities	0.34	0.30	0.32	0.27	0.25	0.45	0.19	**0.302**
Construction Time	0.11	0.10	0.08	0.13	0.15	0.07	0.13	**0.111**
Durability	0.17	0.20	0.16	0.20	0.20	0.11	0.16	**0.172**
Constructability	0.08	0.05	0.05	0.07	0.10	0.06	0.10	**0.072**
Availability of Material	0.07	0.03	0.04	0.03	0.05	0.04	0.23	**0.071**
Safety	0.17	0.30	0.32	0.27	0.25	0.22	0.16	**0.241**
Aesthetic	0.06	0.02	0.03	0.02	0.01	0.04	0.03	**0.031**

Figure 33. Normalized pairwise comparison matrix.

A Consistency Ratio (CR) for the criteria matrix is automatically computed to ensure the reliability of the weighting process. The consistency is determined by using the eigenvalue λ to calculate the consistency index (CI). Consistency Ratios (CRs) are used to measure the consistency of the judgments. Random index values (RIs) are presented in

Table 5. The acceptable amount for a CR does not exceed 0.10. If it is more, then the matrix is inconsistent. The following formulas are used to calculate CI and CR.

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

$$CR = CI/RI \quad (2)$$

where λ is the average of the obtained values by dividing the elements of all priorities' matrices by the priorities vector.

Table 5. Random consistency (RI) [35].

Matrix Size (n)	1	2	3	4	5	6	7	8	9	10
Random Index (RI)	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

The resulting CR of 0.072 falls below 0.10, as shown in Figure 34, thus indicating acceptable consistency in the pairwise comparisons.

Criteria Weight	0.30	0.11	0.17	0.07	0.07	0.24	0.03			
	Funding Capabilities	Construction Time	Durability	Constructability	Availability of Material	Safety	Aesthetic	**Weight Sum Value**	**Ratio**	
Funding Capabilities	0.30	0.33	0.34	0.29	0.35	0.48	0.19	**2.292**	**7.594**	
Construction Time	0.10	0.11	0.09	0.14	0.21	0.08	0.13	**0.860**	**7.730**	
Durability	0.15	0.22	0.17	0.22	0.28	0.12	0.16	**1.322**	**7.707**	
Constructability	0.08	0.06	0.06	0.07	0.14	0.06	0.09	**0.556**	**7.686**	
Availability of Material	0.06	0.04	0.04	0.04	0.07	0.05	0.22	**0.515**	**7.290**	
Safety	0.15	0.33	0.34	0.29	0.35	0.24	0.16	**1.868**	**7.750**	
Aesthetic	0.05	0.03	0.03	0.02	0.01	0.05	0.03	**0.226**	**7.212**	
								λmax=	7.567	
								n=	7.000	
								CI=	0.094	
								CR=	0.072	< 0.1

CHECK
CR < 0.1 OK

Figure 34. Calculating the consistency.

Next, the user inputs alternative pairwise comparison values for each criterion. The model then automatically applies the comparison procedure and evaluates the consistency of the comparisons. To complete the pairwise comparison process, the final score for each alternative is calculated. These comprehensive scores, which synthesize the evaluations across all criteria, are shown in Figure 35, and the most suitable alternative has the highest numerical value.

8.3.7. Development Phase

The results of the alternative evaluation show that ceramic tiles are ranked first as an appropriate alternative with a score of 52.6%, followed by porcelain tiles ranked second with a score of 26.5%, and in the last rank, terrazzo tiles with a score of 20.9%. After selecting the appropriate alternative with a high score (ceramic tiles), the user can go to the BIM model, select this alternative, and apply it to the BIM model, as shown in Figure 36. Selecting this alternative led to a 39% reduction in flooring material costs as the original flooring material (porcelain tiles) cost 375 EGP/m^2 (15.3 USD/m^2) and ceramic tiles cost 230 EGP/m^2 (9.4 USD/m^2).

Criteria Weight	0.30	0.11	0.17	0.07	0.07	0.24	0.03
	Funding Capabilities	Construction Time	Durability	Constructability	Availability of Material	Safety	Aesthetic
Porcelain Tile	0.25	0.24	0.25	0.30	0.30	0.30	0.20
Ceramic Tile	0.50	0.62	0.50	0.54	0.54	0.54	0.40
Terrazzo Tile	0.25	0.14	0.25	0.16	0.16	0.16	0.40

	Funding Capabilities	Construction Time	Durability	Constructability	Availability of Material	Safety	Aesthetic	Score
Porcelain Tile	0.08	0.03	0.04	0.02	0.02	0.07	0.01	0.265
Ceramic Tile	0.15	0.07	0.09	0.04	0.04	0.13	0.01	0.526
Terrazzo Tile	0.08	0.02	0.04	0.01	0.01	0.04	0.01	0.209

Figure 35. The alternative score values.

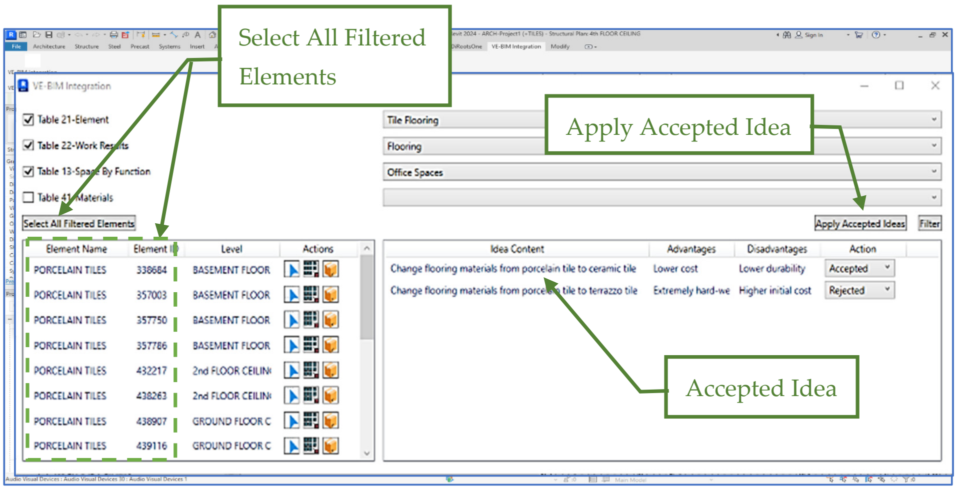

Figure 36. Apply the selected idea to the BIM model.

9. Conclusions

The Architecture, Engineering, and Construction (AEC) industry faces persistent challenges that impede growth and productivity. Despite efforts to digitize the industry, issues such as cost inefficiencies, project delays, and poor decision making remain prevalent. The literature highlights that AEC is one of the least digitally developed industries globally. Although technologies like Building Information Modeling (BIM) and systematic approaches like Value Engineering (VE) have demonstrated potential, their full capabilities remain underutilized. This study addresses this gap by proposing a framework that integrates both BIM and VE, implemented in a prototype model. The framework supports the evaluation and ranking of design alternatives based on multiple criteria, providing decision-makers with valuable tools for optimizing construction outcomes.

The results from the case study demonstrated significant improvements from the integration of VE and BIM, particularly in office building projects. For example, the framework led to a 20% reduction in reinforced concrete (RC) slab costs and a 39% reduction in flooring material costs. These findings underline the benefits of integrating VE and BIM, which can be summarized as follows:

- Centralized data management: the use of a Common Data Environment (CDE) provides a centralized repository for all project data, allowing stakeholders to access and manage information efficiently from any location.
- Efficiency in documentation and calculations: BIM reduces time spent on documentation, quantity take-offs, and cost estimations by automating these processes.
- Enhanced visualization: 3D modeling in BIM aids the VE team in visualizing project elements, identifying areas for improvement, and generating innovative ideas early in the design phase.
- VEIDEA data bank: a structured VEIDEA data bank, based on the OmniClass classification system, allows for efficient storage, management, and retrieval of VE ideas, improving the decision making process.
- Improved design process: the VE–BIM integration add-in assists design teams in reviewing past VE ideas and making informed decisions during the design phase, saving time and improving outcomes.
- Streamlined VE study: the VE–BIM integration add-in also aids VE teams during the Value Engineering study by providing easy access to past ideas and enabling a more efficient review process.
- Automated decision making: the use of the Analytical Hierarchy Process (AHP) in the evaluation phase automates the ranking of alternatives, helping to prioritize design solutions based on multiple criteria.
- Accurate cost estimation: linking the BIM model with MasterFormat classifications allows for more accurate and reliable cost estimates throughout the Value Engineering process.

The findings from this study align with previous research on the advantages of integrating VE and BIM in construction projects. The synergy created by combining these approaches, supported by a Common Data Environment, has the potential to transform the construction industry by improving efficiency, reducing costs, and enhancing project outcomes. This framework equips designers and VE teams with the tools necessary to develop cost-effective buildings that meet client requirements.

In terms of its contribution to the field, this study represents the first comprehensive attempt to integrate BIM and VE within a Common Data Environment for pre-construction decision making. The practical implications for industry professionals are significant, as the framework offers clear benefits in terms of integration, visualization, structured data management, and automated evaluation.

10. Limitations and Future Research

Several limitations were identified in this study. First, the model was restricted to office building projects, which may limit its generalizability to other types of construction projects. Second, the successful implementation of the VE–BIM integration add-in and Revit model template depends on their availability to the design team from the outset of the project. Third, newly introduced VE ideas require the user to create or modify elements in the Revit model template to ensure compatibility with the VEIDEA data bank. Finally, structural alternatives often necessitate changes that require the involvement of designers.

Future research should focus on extending this framework to other project phases beyond pre-construction and applying it to different types of construction projects. Additionally, incorporating artificial intelligence (AI) tools into the framework could enhance its decision making capabilities, particularly for complex projects where multiple criteria must be balanced.

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