A Proposed Framework for The Integration of Value Engineering and Building Information Modeling

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ABSTRACT

An increasing number of initiatives are being implemented to ensure the effectiveness of construction projects as their scale and complexity increase. Value Engineering (VE) and Building Information Modelling (BIM) are used as strategies to cope with large-scale and complex construction projects. VE involves a multidisciplinary team in a systematic workshop focused on improving the project function. VE is applied during the pre-construction phase where benefits can be maximized. The implementation of VE can be more effective with utilizing BIM, especially in providing accurate and adequate information. This paper explores the integration of Value Engineering (VE) and Building Information Modeling (BIM) within the Architecture, Engineering, and Construction (AEC) industry. This study proposes a framework that aims to systematically implement VE in construction projects by leveraging BIM and Common Data Environment (CDE) technologies. This framework consists of four main modules: (1) Upload project data into CDE, (2) 3D Design BIM model development, (3) Value Analysis / Engineering model, (4) Detailed Value Engineering Study. The integration aims to improve project outcomes, reduce costs, and facilitate better collaboration and communication among stakeholders. The benefits of the use of this structured approach include automating tasks such as quantity takeoff and cost estimating, utilizing 3D models for visualization, develop structured database which could manage, store, search, and share the past VE ideas among team members and applying the VE at the pre-construction phase, to avoid potential major redesigns, and more opportunities for improvement can be implemented.

Keywords: Value Engineering (VE), Building Information Modeling (BIM), Common Data Environment (CDE), Integration, workflow, Complex projects.

1. INTRODUCTION

In the AEC (Architecture, Engineering and Construction) industry, function, performance, cost and value of the project are substantial considerations when project owners make decisions (Wao, 2014). The project value can be assessed by the ratio between function and cost. Construction activities are expensive and frequently associated with cost overrun and delays (Abdelalim et al., 2019). Value Engineering (VE) is used to improve project performance and reduce life cycle costs. VE is a systematic and innovative approach that examines the project's needs to achieve the desired functionalities at the lowest overall cost. The success of the VE study is mostly decided by the successful communication and planned activities of the multidisciplinary VE team. The evaluation of generated alternatives is a key use of VE. VE analyses the building components and their functions, generates alternatives, selects the most optimal alternatives, and implements them. Building Information Modeling (BIM) is an innovative technology employed to address challenges such as low productivity in the architecture, engineering, and construction sector (Abbasnejad et al., 2020). BIM provides crucial benefits over the whole duration of the construction project (Ali Mohamed et al., 2020). highlighted that BIM technology produces a very detailed digital representation of a building (Saraireh & Haron, 2020). This model can be widely utilized in planning, design, construction and operation. In addition, BIM has proven its capacity to enhance efficiency and productivity during the design phase. Integrating VE implementation into the BIM preparation process may guarantee seamless project execution.

According to (Altaf et al., 2021), limited studies has been conducted on the integration of VE in the construction projects with BIM. Furthermore, (Baarimah et al., 2021) noted that for practitioners managing construction projects there are no specific frameworks for effectively utilizing this integration. As a result, this paper aims to propose a framework for the integration of VE-BIM that will help the practitioners in the construction sector to apply the VE in systematic manner to optimize cost and improve the project performance and value.

2. VALUE ENGINEERING

The value engineering process (VE) is carried out in accordance with the VE job plan, which consists of a series of interdependent phases. The VE job plan begins with the information phase followed by the function analysis phase, the creativity phase, evaluation phase, the development phase and concludes with the presentation phase as illustrated in Figure 1. It is essential to follow the prescribed sequence of phases in the VE study, as they are interdependent. Each phase builds upon the previous one, making it imperative to follow the specified order. Each phase encounters sequential processes to be implemented throughout the value engineering study (Abdelalim, 2018). Furthermore, the data gathered during the initial phase (the information phase) plays a vital role in subsequent phases, ultimately leading to the completion of the study. The implementation of the VE enhances quality, performance, safety, durability of the project (Abd-Elhamed et al., 2020).

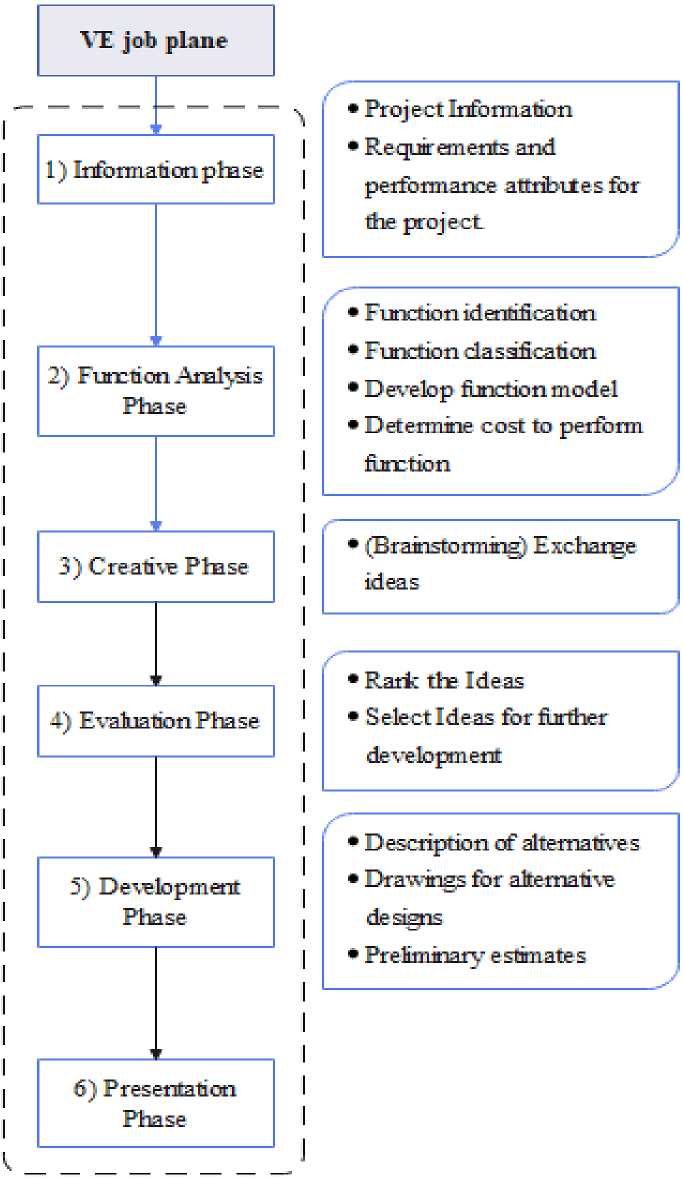


Figure 1: Value Engineering job plan.

3. THE CONCEPT OF BIM

In the 1970s Charles M. Eastman introduced the concept of BIM and its development took place in the 1980s and 1990s (Wong et al., 2011). BIM is known as Building Information Management or Building Information Modeling, (Czmoch & Pękala, 2014). BIM is an integrated representation of a structure, capturing geometric as well as process-related information which allows the stakeholders to work collaboratively during a construction project's lifecycle. It has a computable representation of all the building characteristics and associated data, which is serving as a repository for building information to be used throughout the project lifecycle. BIM is a 3D digital representation of building objects, including their physical geometry (2D or 3D) and its functional parameters, (Azhar, 2011). As the team members work on the model, they refine and adjust it continuously based on design modifications and project specifications to ensure its accuracy before construction phase begins. After finalizing the BIM model, precise quantity surveys, item counts, construction scheduling, and space dimensions can be obtained at any design phase. Additionally, BIM generates a list of components, enabling the cost estimates to be evaluated during the design process rather than at the end of the projects, as it was customary in the traditional practices, (Eastman et al., 2011).

3.1. BENEFITS OF BIM IMPLEMENTATION FOR VALUE ENGINEERING

Most of the leading (AEC) firms have recognized the benefit of implementing the BIM technology in the construction projects, which shift away Computer Aided Design (CAD) system, (Farouk & Rahman, 2023). The collaborative capabilities of BIM across various disciplines have resulted in expanded its application in the industry in recent years. The (BIM) with (VE) provides numerous benefits such as enhancing the overall value and efficiency of construction projects. BIM's capabilities offer a comprehensive and detailed representation of a building's physical and functional characteristics, which aligns with VE's objective to maximize project value by optimizing costs and improving project performance. The implementation of BIM brings numerous benefits to construction projects, making it a significant motivator for its adoption, (Hong et al., 2019).

The main benefit of BIM implementation is the ability to provide an accurate 3D geometrical representation of a building within an integrated data environment (Azhar, 2011). Moreover, here are key benefits of using BIM for Value Engineering:

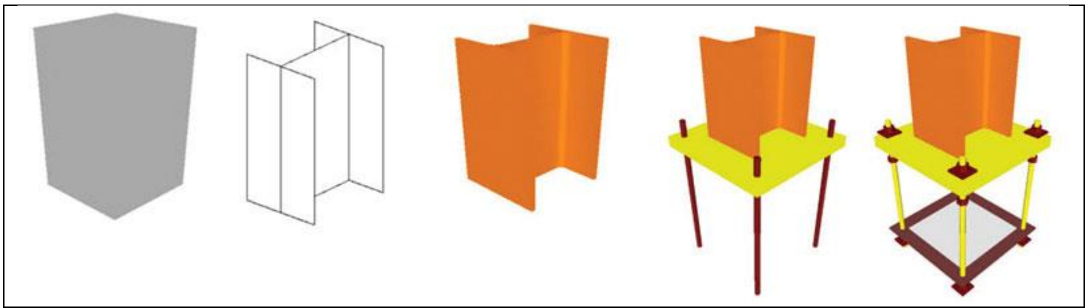
- BIM enhance the collaboration and communication among project stakeholders (Zhi-Min & Ma, 2021).
- BIM increases project efficiency and productivity, with less rework during construction phase (Tan et al., 2019).
- BIM helps in facilitating the selection of sustainable materials, while reducing material wastage and project environmental impacts (Chan et al., 2019).
- Establish an integrated tracking system for analyzing workers' workplace behavior using the BIM environment (Abdelalim & Said, 2021a).
- Integrating dynamic data such as existing conditions, sensor measurements, control signals, etc., into BIM models can help in analyzing building operations and maintenance (Abdelalim & Said, 2021b).
- Enhanced decision-making process and help in early identification of design and construction issues.

3.2. BIM LEVEL OF DEVELOPMENT (LOD)

The Level of Development (LOD) refers to the degree of reliability and accessibility of both geometric and semantic information in a BIM project, which reflects the incremental availability of information during the design stage. LOD plays a critical part in the BIM project execution plan (BEP) (Shawky et al., 2024) and in most cases is contractually binding (Abualdenien & Borrmann, 2022). In 2008, the LOD was introduced by the American Institute of Architects (AIA), which consist of five levels starting from LOD 100 to LOD 500. From 2013, the BIMForum working group has investigated the AIA definitions in detail and introduced LOD 350, followed by annual updates to the LOD specification. The five levels of development, as defined by BIMForum, are as follows (Bedrick et al., 2021):

- **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.
- **LOD 350** (**Construction Documentation**); including the interfaces between all the building systems.
- **LOD 400** (**Fabrication and Assembly**); the model includes the information related to detailing, fabrication, assembly, and installation.
- **LOD 500** (**As built**); the model elements are a verified representations with the construction site in terms of quantities, location, shape, size, and orientation.

An example of Steel Framing Column is shown in Figure 2, illustrating the progression of design across the LODs, in accordance with the BIMForum's specifications.



LOD 100	LOD 200	LOD 300	LOD350	LOD 400

Figure 2: The LODs for steel framing column (Bedrick et al., 2021)

4. CONSTRUCTION CLASSIFICATION SYSTEMS

Efficient communication among project participants is crucial for the successful execution of a construction project, and that requires easy access to essential project information. Efficient information organization and retrieval is improved substantially when a standard filing system is used by everyone. Classification system offers a means to add structure to the disorganized data and information generated throughout the project life cycle. This structure enables the users to narrow searches, to present information in a way that makes sense to the receiver, and to retrieve asset object groupings without specific knowledge of the objects composing that grouping.

Various classifications have been used for many years in the AEC industry to organize building information. the chosen Methods are depending on the project phase and level of details required. The preliminary phases of the project cycle require more generalized organization than the detailed information required during the later phases. Figure 3 illustrates the project phases and the related construction information standards. The adapted classification system in this research is “OmniClass”.

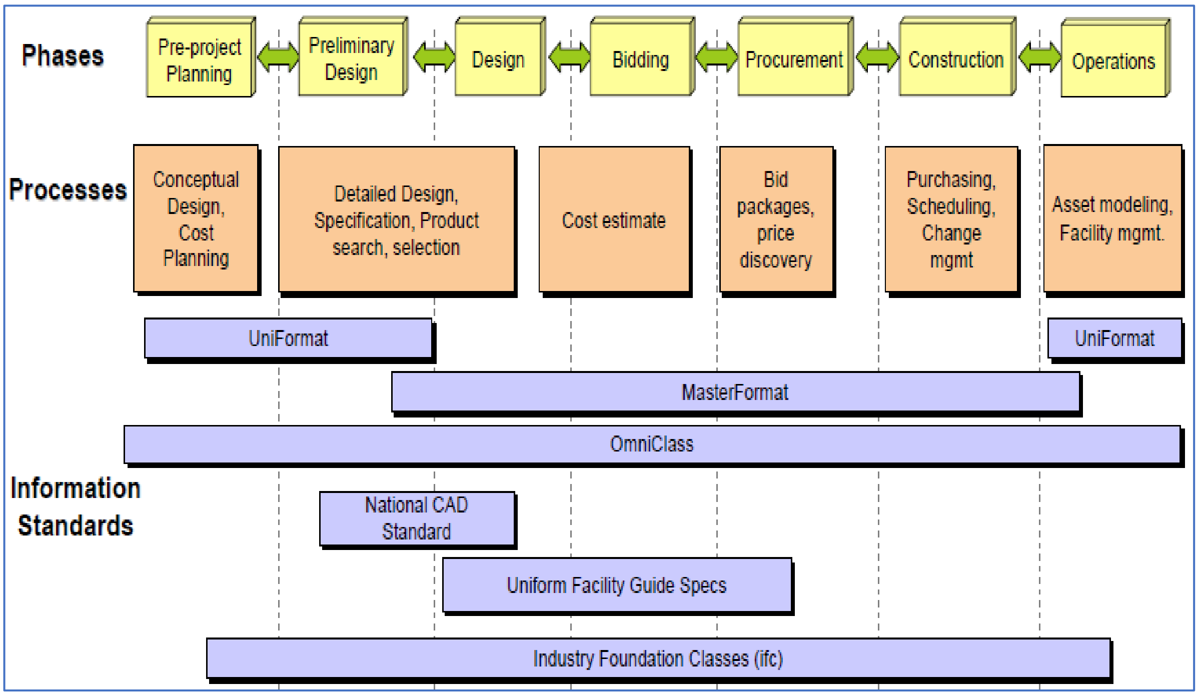


Figure 3: Construction Information Standards by Phase

4.1. OMNICLASS CLASSIFICATION SYSTEM

OmniClass is a classification system used for the construction industry which has various applications, such as organizing project information, However, its primary application is to provide a classification structure for electronic databases and software, enhancing the data utilized in those resources, (CSI, 2012). OmniClass is compatible with different classification systems as it incorporates other classification systems as the basis of two of its Tables, MasterFormat for (Table 22- Work Results) and UniFormat for (Table 21– Elements). This allows for easy data integration from multiple classification systems into the BIM models, (Afsari & Eastman, 2016).

OmniClass includes content from various categories of construction such as buildings, horizontal construction, process plants and industrial construction, heavy civil projects, and even single-family residential construction. This wide coverage allows for organizing, filtering, sorting, and retrieving information, and standardizing digital data exchanges. OmniClass consists of 15 tables as presented in

Figure 4, with each table representing a different aspect of construction information. Each table has the capability independently to classify a specific type of information, or it can be combined with other tables to classify an item that is not currently included, (Afsari & Eastman, 2016).

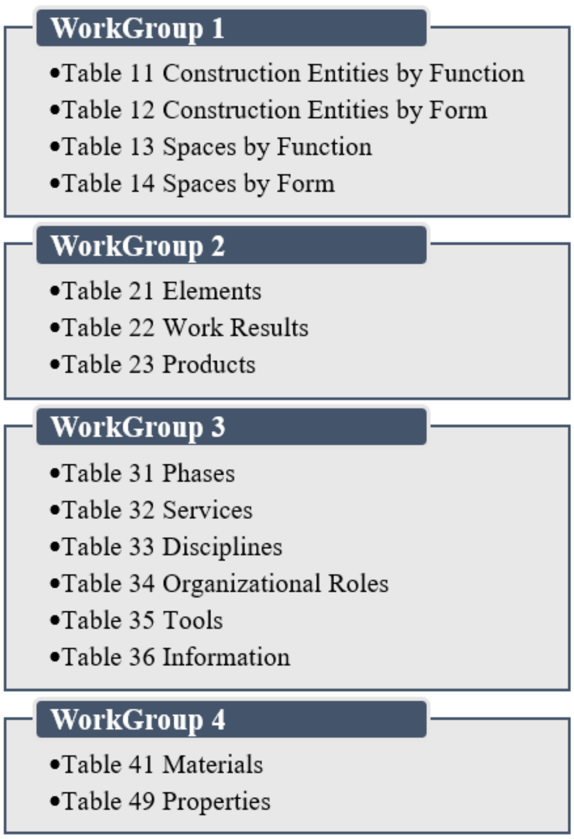


Figure 4: The 15 OmniClass tables.

Table 1 presents an example for the OmniClass classification from Table-13 (Space by Function) for the parking spacing.

Table 1: Example of OmniClass Classification-Table 13 (Space by Function)

OmniClass Table 13	Spaces by Function (May 2012)
13-21	Parking Spaces
13-21 11	Exterior Parking Spaces
13-21 11 11	Exterior Parking Circulation
13-21 11 13	Exterior Parking Access Control Point
13-21 11 15	Exterior Parking Stall
13-21 13	Interior Parking Spaces
13-21 13 11	Interior Parking Ramp and Circulation
13-21 13 13	Interior Parking Access Control Point
13-21 13 15	Interior Parking Stall
13-21 13 17	Interior Vehicle Service Space

5. COMMON DATA ENVIRONMENT (CDE)

According to ISO 19650-1, the CDE is a centralized platform for managing and sharing information related to a project or asset. It facilitates collaboration and coordination among different teams and stakeholders by collecting, organizing, and distributing all information in a structured manner.

The workflow of the CDE in Figure 5 illustrates the various status of the information containers.

1. **The Work-in-Progress (WIP) state**

"*The WIP state applies to information that is still being developed by its respective task team, such as drafts, design concepts, and unverified data. During this stage, the information should not be accessible or visible to any other team.*"

2. **The Shared state**

"Once the design data has been reviewed, checked, and approved, coordination among various disciplines takes place. At this stage, the shared model is accessible to all other project disciplines, enabling them to work on the most recent data and information."

3. **The Published Documentation state.**

"Client approval and authorization of the shared information precedes the creation of the published documentation to be used by all project participances."

4. The Archive state.

"All approved data must be stored in a designated archive location for future retrieval as needed."

According to, (Stransky, 2020), it is a common misconception to view CDEs solely as a digital platform for storing and exchanging information. Instead, CDEs offer much more, including BIM project management, status and workflow management, and monitoring of construction site progress. Hence, CDEs serve as a collaborative environment for managing and coordinating various aspects of a construction project, rather than just a simple data storage and sharing tool.

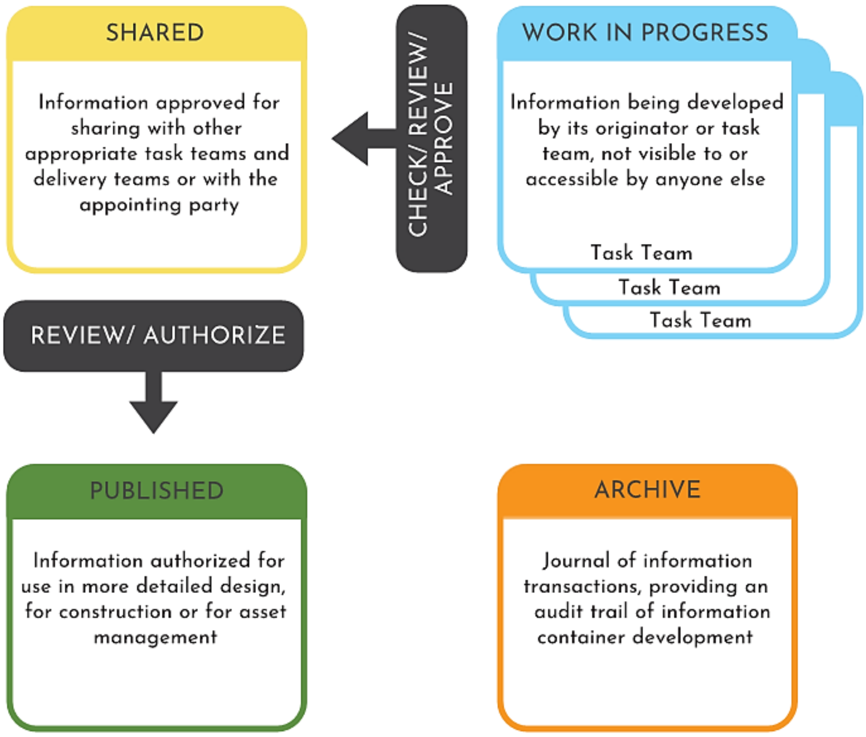


Figure 5: The workflow of the CDE according to ISO 19650-1

5.1. UTILIZING THE BENEFITS OF BIM AND CDE IN CONSTRUCTION PROJECTS

BIM models nowadays are essential in construction projects, and the use of CDE can help improve their management and collaboration. By integrating BIM models within the CDE and creating a single source of truth, project stakeholders can access the latest design information, collaborate on model revisions, and extract data for analysis and reporting. Also, with access to comprehensive BIM data, project teams can make informative decisions, visualize project progress and identify potential clashes or issues. BIM rich data environment provides valuable insights for ongoing maintenance and facility management, improving the lifecycle management of built assets. This integration ensures that BIM remains at the core of project delivery and assets management.

6. THE IMPLEMENTATION OF THE TRADITIONAL VALUE ENGINEERING

The implementation of the traditional value engineering is challenging as it requires extensive workshops that can be time-consuming. The successful completion of the value engineering study necessitates extensive organization and coordination among team members in order to efficiently navigate the extensive hours spent in the workshops. Furthermore, the VE study generates a substantial amount of documentation, hence requiring the implementation of an organized system for the retrieval of the required data, especially in large projects. The VE team must possess a high level of expertise in their respective fields so they can manage this amount of paperwork that will be produced during the study and be innovative enough to generate ideas. Consequently, there is a need for a tool to enhance the implementation of value engineering and assist the VE team to be more innovative. Therefore, there are areas where improvements in value engineering studies can be concentrated, as listed below:

1. Reducing the time for Documentation and Calculations; Implement more efficient tools or software to help automate certain tasks such as quantity takeoff and cost calculation.
2. The absence of a well-organized database management system capable of effectively managing past VE ideas;
   - Develop a systematic approach to store and manage past VE ideas.
   - Implement organized database where ideas can be stored, searched, and shared among team members.
3. Utilizing 3D Models for Visualization;
   - Integrate the use of 3D modeling technology to assist the value engineering team in visualizing the project.
   - This will help team members understand proposed ideas more comprehensively and identify potential areas for improvement.
4. Early Integration of Value Engineering in the project life cycle;
   - By involving the value engineering team from the beginning, preferably during the design phase, so that potential major redesigns can be avoided and more opportunities for improvement can be identified.
   - Facilitate collaboration between designers and the value engineering team to ensure seamless integration.

The following section will present the proposed framework for the integration of VE with BIM. The BIM technology and CDE will be used as a tool to enhance the implementation of VE study.

7. THE PROPOSED FRAMEWORK FOR THE INTEGRATION OF VE AND BIM

The proposed framework will be implemented during the in the preconstruction phase. It is crucial in the preconstruction phase that the stakeholders and design team 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 (Abdelalim et al., 2021). These issues tend to lead to significant problems during the construction phase as shown in Figure 6.

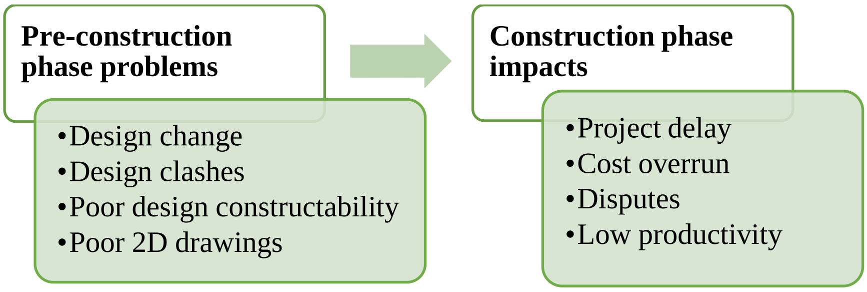


Figure 6 : Pre-construction phase problems and their construction impacts.

The proposed framework consists of Four main modules as presented in Figure 7. The modules are as follows:

1. Upload project data into CDE.
2. 3D Design BIM model development.
3. Value Analysis / Engineering model.
4. Value Engineering Study.

The goal is to select the most appropriate alternative by considering multi-attributed criteria that satisfy owner requirements and project objectives.

7.1. MODULE 1: UPLOAD PROJECT DATA INTO CDE.

The CDE functions as a single source of truth for all project information, offering secure document storage and digitalized repositories for all kinds of document relevant to the project including PDFs, spreadsheet, and AutoCAD Drawing (.dwg) files. This centralized repository facilitates accessible and organized project information for all participants.

List of the 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 key milestones.

On the other hand, The VE Idea Bank database is designed to store and manage VE ideas. The database can be created by transferring the traditional/existing VE ideas into VE Idea Bank database with the Omniclass classification. The database will include general and detailed information about the VE ideas.

The VE Idea Bank database consists of two sections of VE ideas information which are general and Detailed information.

- The General information consists of information including the idea number, idea contents, date, VE study areas, as well as advantages and disadvantages of each idea.
- The Detailed information consists of the Omniclass classification values related to each idea classified by Elements, Space by Function, Work Results and Materials. All project information and documents along with the VE idea bank database will be stored in the CDE for easy access from all the project parties.

7.2. MODULE 2: 3D DESIGN BIM MODEL DEVELOPMENT

3D BIM models provide the users with the ability to visualize objects and structures in a three-dimensional format. This representation enhances users' comprehension of the project and minimizes the chances for misrepresenting elements. 3D views enable the VE team to preview the project prior to the construction. This will assist the members of the VE team in generating a greater number of innovative ideas. It is very important for the design team to determine the required LOD (Abdelalim & Abo. Elsaud, 2019). The 3D BIM model will progress through different levels of development, starting with LOD 100 (Conceptual Design), advancing to LOD 200 (Schematic Design), and finally reaching LOD 300 (Detailed Design). At this stage, the model contains:

- 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

The cost data is added for each element into the 3D BIM model. Adding the cost data into the 3D BIM Model will increase the dimension of the model to fourth dimension (4D). Subsequently, new shared parameters (Table 13-space by function, Table 21-Elements, Table 22-Work results, and Table 41-Materials) will be created and added to the BIM model. Once completed, the new parameter values could be added to the BIM model as a shared parameter through editing Revit families as presented in Figure 8.

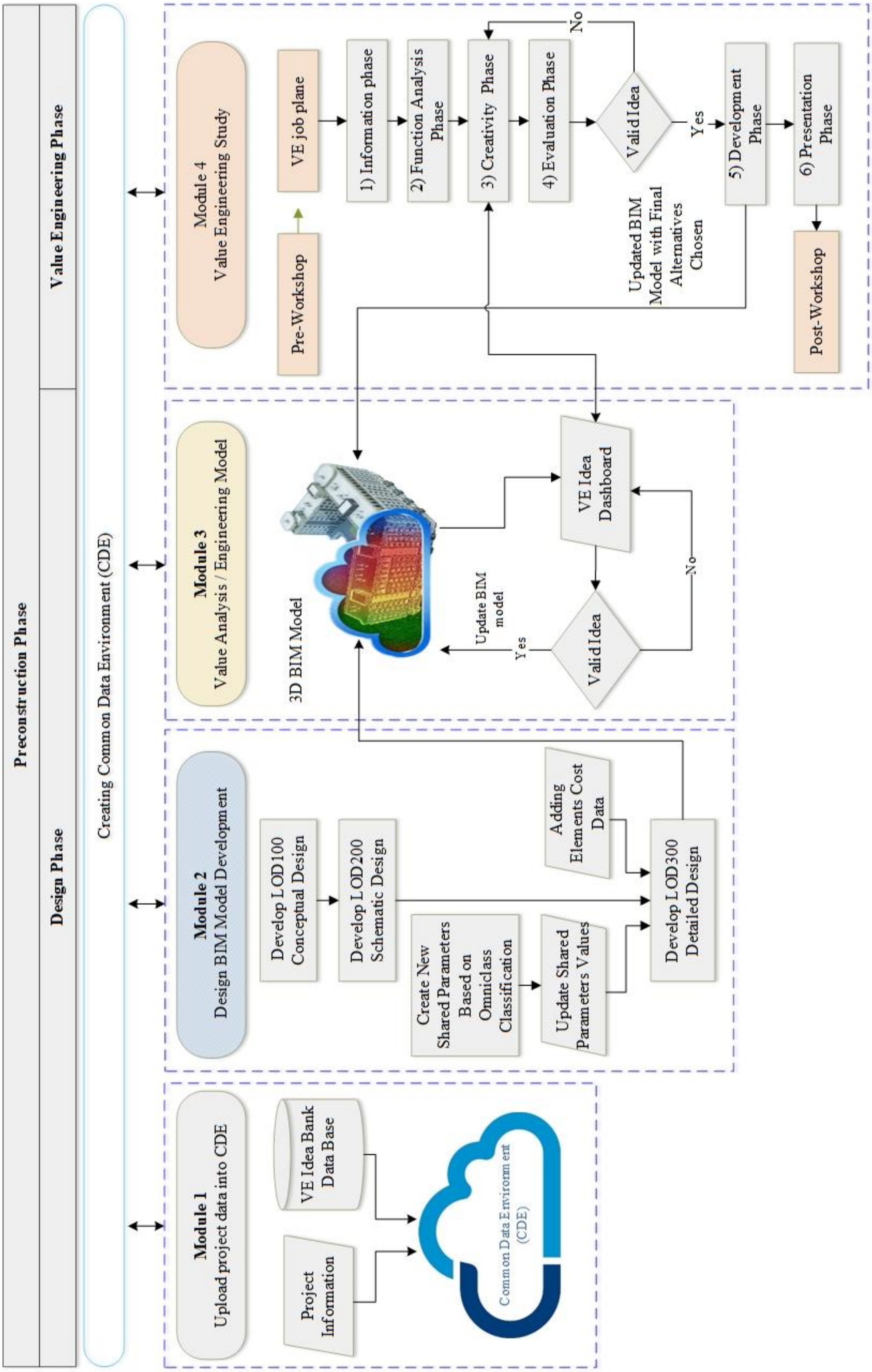


Figure 7 : The Proposed Methodology for the integration of VE and BIM

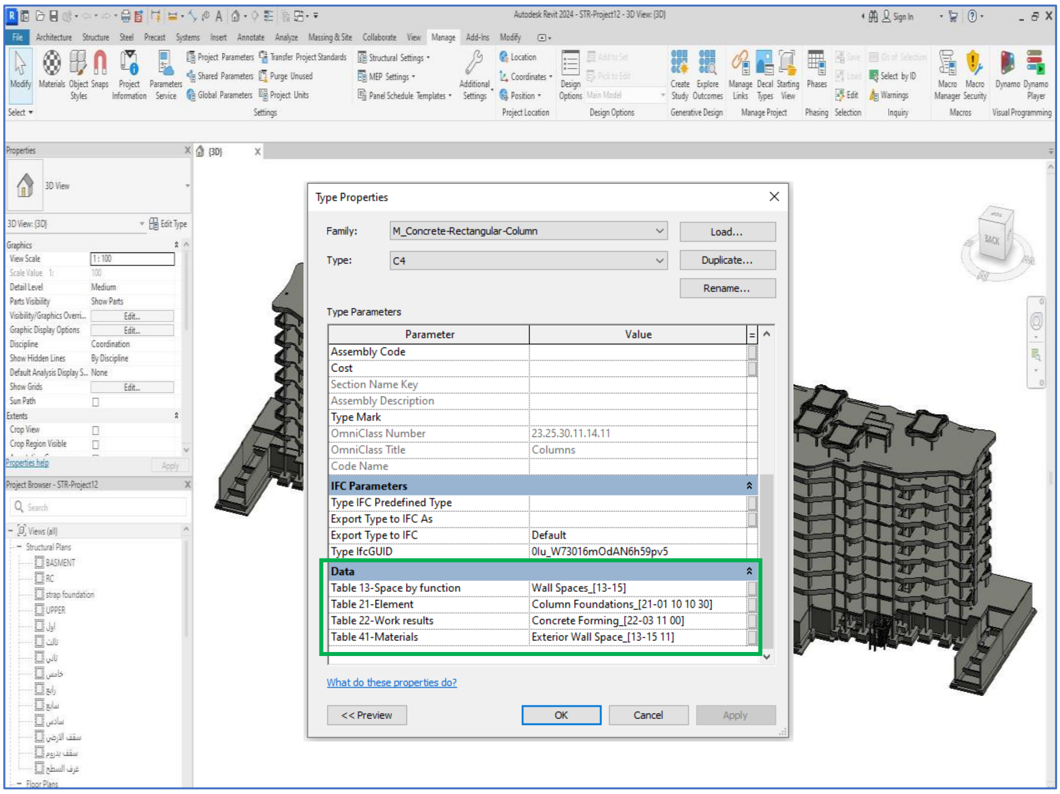


Figure 8: Concrete column property after including the new parameters.

7.3. MODULE 3: VALUE ANALYSIS / ENGINEERING MODEL

During the design development phase, the established idea bank database will be linked with the BIM model containing pre-assigned OmniClass parameter values for all elements. This enables a facilitated search for past VE ideas stored in the database related to any specific object within the BIM model. To refine the search criteria for retrieving relevant VE ideas, utilization of various search parameters that include Elements, Space by Function, Work Results and Materials. After reviewing the ideas, the selected idea could be implemented by directly modifying the BIM model.

This module will allow the design team to integrate past VE ideas systematically into the ongoing design development process. Consequently, this proactive approach potentially reduces the need for extensive design changes that may occur after completing the design. Additionally, this approach helps comprehension the designs through 3D visualization and enhances the effectiveness of VE implementation.

7.4. MODULE 4: VALUE ENGINEERING STUDY

The implementation of value engineering essentially relies on the collective expertise and innovative thinking of the VE team. The purpose of the proposed methodology is not to remove humane creativity, but the main objective is to facilitate the execution of the value engineering study which will save time and effort. The objectives are as follows:

1. Assist the user to go through the value engineering job plan in a systematic way.
2. Reduce amount of paperwork during the value engineering study as all the calculations such as quantity takeoff, cost calculation and the evaluation will be carried out by the model.
3. Reduce the timing and execution of the VE workshop studies.
4. Saving the data in an organized way to be easy to retrieve any information.

The ideas bank database will contain the previous ideas and the new ones generated during the study that will be available to the user to retrieve at any time.

The value engineering process is implemented by following certain job plan. Following the phases of the value engineering study with their order is very important as they are based on each other according to this sequence as illustrated in Figure 9.

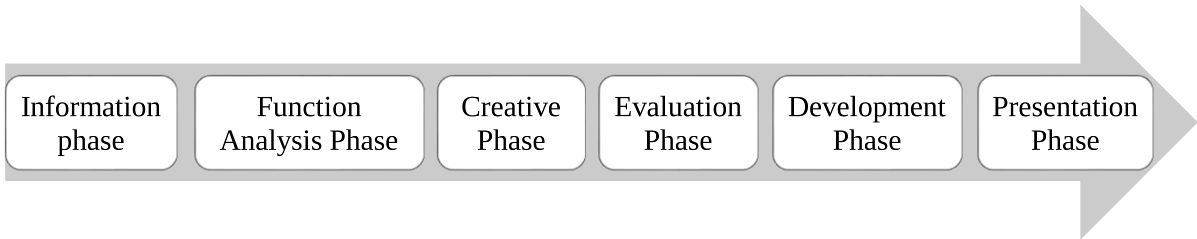


Figure 9: Value engineering job plan.

The VE process commences upon the formation of the VE team. The first step of 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. 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. Afterwords the function analysis phase begins by using the Functional Analysis System Technique (FAST) to define the project scope and clarify the basic functions that must be maintained. Then, ideas would be generated, and the best ones would be selected for further development.

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

8. CONCLUSION

This paper proposes a framework for integrating value engineering and building information modeling by leveraging the use of a CDE which comprises of four modules (1) Upload project data into CDE, (2) 3D Design BIM model development, (3) Value Analysis / Engineering model and (4) Value Engineering Study. This framework offers a more efficient, effective, and collaborative approach to project delivery, with the potential to improve project outcomes, reduce costs, and promote collaboration and communication among project stakeholders. The proposed framework has outlined the path for systematically implementing the VE in the construction projects while leveraging the benefits of BIM and CDE for the VE participants and assist the designers in the design phase to improve their design and avoid any potential design modifications after finalizing the design. A framework was presented to illustrate the full picture of integration between VE and BIM. It is hoped that this research will become a stepping-stone towards further research in this field.

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