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Building Information Modeling and Value Engineering for Project Schedule and Cost Control

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Architectural, Engineering, and Construction industry personnel continuously face challenges in executing projects within budget and schedule. Scheduling and cost control are vital processes for achieving project success. A study proposed a framework for integrating building information modeling (BIM) and value engineering (VE) processes to enhance value, minimize costs, improve schedules, and ease information exchange. A case study building project was used to demonstrate how BIM and VE integration can be harmonized and validate the proposed method. The findings showed that using BIM and VE improves design modification and detailed data extraction, e.g., cost, schedule, etc. The outcome indicated the significance of using both BIM and VE to enhance project functionality, performance, and team coordination throughout the project lifecycle. This study provided the value of the integrated BIM and VE, including understanding the project requirements, improving team dynamics, seamless data exchange, and a comprehensive understanding of linking weighted and functional analysis to BIM processes and validated recommended project solutions. The proposed framework provided an option for virtually evaluating design changes and reducing errors during construction.

Key Words: Building Information Modeling, Case Study Project, Construction Schedule, Cost Control, Value Engineering

Introduction

The value engineering (VE) process presents opportunities to remove unnecessary costs while ensuring quality, reliability, performance, and improvements resulting from multidisciplinary teams' recommendations (Wao, 2015). VE defines a rigorous and structured effort to optimize the designed building features, materials, and equipment selections to achieve vital functions at the lowest life-cycle cost. The VE approach generates cost improvements without sacrificing the required project quality levels. Different levels of experts across the architectural, engineering and construction (AEC) industry have used VE effectively to improve decision-making (Wao et al., 2017). Ranjbaran and Moselhi (2014) presented an automated 4D-based VE model for design professionals, owners, and VE teams to assess and compare different design alternatives using multi-attribute criteria. The model was applied to a case study project to rank other options and choices. The results supported cost-driven decision-making with different design alternatives.

The execution of VE has been consistent in many construction projects beyond the planning, design, and post-construction phases including maintenance and operation (Pour et al., 2020). These factors affect the cost of construction projects which increases the difficulty of cost control and management. VE applications in building projects remain limited owing to the large scale of information exchange making it difficult to conduct a desirable VE process. The life cycle of building projects and the continuous increase in risk factors are not conducive to the development of VE (Wen, 2014). VE application alone is insufficient for effective cost control and schedule management. Therefore, there is a need to introduce building information modeling (BIM) to complement the effort.

Taher et al. (2019) investigated BIM-VE integration in the construction industry using a case study approach and at the design stage only. This paper aims to further this effort by providing a framework for using BIM and VE applications simultaneously during the design to post-construction phases using a case study approach. The literature review discusses VE, BIM and related integration of both.

Literature Review

Value Methodology

Several factors and roadblocks can lead to unnecessary costs. The team approach is a proven way to overcome these roadblocks and concentrates on problem-solving techniques to overcome obstacles (Jongsik & Seunguk, 2018). VE builds a cohesive team of self-motivated individuals committed to achieving common goals. The VE process, also called Job Plan, drives the team's planned VE effort, leading to improved decision making to realize the optimal expenditure of owner funds while meeting the required functions at the most favorable value. Simultaneously, the owner's desired tradeoffs, such as aesthetics, environment, safety, flexibility, reliability, and time, are considered (Wao et al., 2017).

The traditional VE job plan comprises of the following steps (Wao, 2015):

1. *Information phase*: This phase brings all team members to a standard basic level of understanding of the project, including tactical, operational, and specific aspects of the subject. Functional knowledge establishes the base case to identify alternatives and mismatches and sets the agenda for innovation.
2. *Function analysis*: This phase focuses on validating that the project satisfies the needs and objectives of the owner. The function analysis provides a more comprehensive understanding of the project by focusing on what it does and must do rather than what it should be. The team identifies value-mismatched function(s) to focus on improving the project value.
3. *Creativity Phase*: The team creates an array of ideas that provide a wide variety of possible alternative ways to perform the function(s) to improve the value of the project.
4. *Evaluation phase*: The team evaluates the alternatives using some criteria and select the most preferred alternatives from the list of options.
5. *Development Phase*: The Value Study team develops selected alternatives and low-, medium-, and high-risk scenarios, and offers these alternatives to senior management for consideration.

BIM and its Application

BIM has gained significant traction in the AEC industry. The BIM technology allows for a concise virtual design model to be digitally assembled and constructed. BIM helps AEC industry actors to visualize a simulated building before actual construction. This pre-planning activity helps in identifying potential design, construction, and operational problems.

According to Azhar et al. (2011), BIM represents a new paradigm within the AEC industry; it encourages the integration of stakeholders' roles in evaluating the advantages and disadvantages of applying BIM methodology in the preparation and coordination of building designs and computational tools. To accurately measure BIM application capabilities in construction enterprises, a study proposed an evaluation framework model based on interval gray cluster analysis (Jongsik & Seunguk, 2018). The study results indicated that the proposed model could provide a new approach to improving application capabilities. The application of BIM supports construction cost estimation and lifecycle cost for critical decision-making in the early phase of building projects (Jaewook et al., 2020). A 3D-BIM on-site performance measurement system enables project managers to recognize performance or job-site productivity in real-time, making the BIM application a unique process to reduce waste at the project site (Baarimah et al., 2022). The AEC industry is rapidly accepting BIM applications to reduce costs, and time, and improve environmental sustainability.

A study benchmarked the current status of BIM implementations, organizational structures, training requirements, and strategies for companies and examined the expectation of BIM knowledge and skills (Kihong & Mojtaba, 2011). The findings supported BIM growth as an essential component of construction operations. The researchers provided a benchmark for measuring the transformation of BIM practices in construction companies over time and across different sectors. In addition, the study provided essential information that informs university construction curricular efforts. Another study investigated effort where not using BIM model (geometrical model) at tender/bidding stage may increase the digital gap throughout the project life (Bucknall, 2021). The study traced the benefits of receiving BIM/Geometrical models at procurement (tendering/bidding) phase to thorough design interrogation, enabled class detection, risk reduction & allocation, efficient quantity take-off and safe construction sequencing including optimization of biddability. The benefits included embracing digital collaboration during procurement phase and the design team's willingness to share BIM models to support procurement. BIM can also be used to simulate important aspect of facility from the perspective of three geometrical dimensions of building (Ershadi et al., 2021). These dimension aspects include time (4D), cost (5D), energy (6D), sustainability (7D), safety (8D), lean construction (9D), and industrialized construction (10D). In their assessments, it was found that 4D, 5D, 8D and 9D BIM to be more significant during design and construction stages.

BIM and VE Integration

Controlling the construction schedule and cost are critical steps in ensuring a project's success and increasing its value (meeting the owner's requirements). Stakeholders have been widely applied BIM in construction projects to minimize total costs. BIM capabilities may present an excellent opportunity to facilitate the VE process from the early project phase. Baarimah et al. (2022) conducted a bibliometric analysis to ascertain the advantages of BIM and VE integration. The outcomes showed that VE and BIM help in decision-making concerning the cost-earned value and support increased prominence as mainstream topics associated with the construction industry.

The crucial phase in VE applications is the evaluation of generated alternatives with defined criteria. Designing an automated approach to evaluate and compare these alternatives helps stakeholders utilize multi-attribute criteria to integrate the designed models with visualization capabilities and easy decision-making processes. Demirdöğen et al. (2021) developed a maturity framework to facilitate the AEC industry and identify open challenges. The results indicated that BIM integration with VE is a prominent application for construction waste reduction. Al-Gahtani (2022) comprehensively reviewed recent VE studies to identify VE application challenges and probed the existing automation knowledge gap. The study identified solutions for owner value addition. According to Zhang and

Gohory (2022) proposed automated system, decision-makers need to enhance the design's ability to meet stakeholders' values and encourage synergy between the VE team and other project members. Another study used weighted evaluation technique to evaluate construction system in comparison with an alternative. The study recommended weighted evaluation technique as a safe approach for criteria scoring matrix for value alternatives (Agrama et al., 2014).

Research Methods

The study focused on providing a framework to harness BIM and VE applications during the design to post-construction phases using a case study project. The case study required a functional analysis system technique (FAST) which details how to display functions in a logical sequence to prioritize tasks and test their dependencies (Wao et al., 2017). The aim was to develop a framework for using BIM and VE processes to improve value, minimize cost, and schedule through an expanded model for alternative material selection and seamless information exchange. The specific objective was to determine VE and BIM effects on overall value propositions for the proposed case study project.

Integrated BIM-based VE Framework

Figure 1 shows the integration of the BIM-based VE automated framework into an integrated repository of a distinct database for design alternatives. The proposed framework contributes to the execution of alternative analysis by selecting suitable design alternatives.

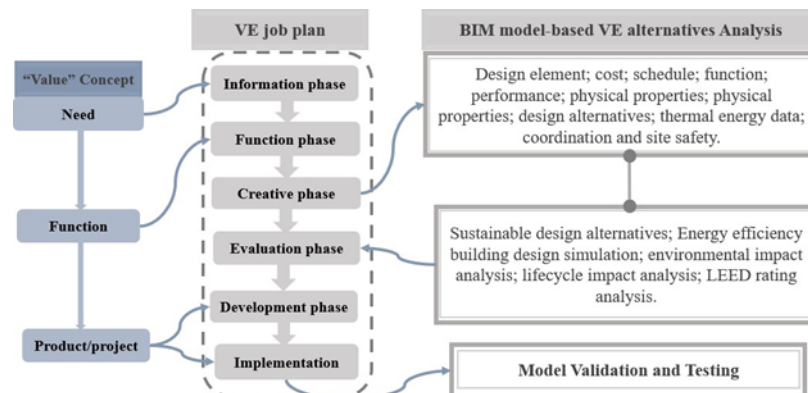


Figure 1. BIM-based methodology framework for integrating BIM and VE

The framework starts by implementing the VE job plan, including the information, function analysis, creativity, evaluation, and development phases. Automation of the framework was developed through 3D, cost (4D), and schedule (5D) models to facilitate smooth alternative generation. BIM models favors the elimination of old methods of importing all data into one drive/dropbox/desktop system (Amoah, 2022). The research supports the idea of a new system based on CAD-BIM integration with extended connection through automated platform to enable automatic linking with other application. The automated BIM Based framework serve as a platform for analyzing design alternatives and further extracting the cost, schedule, and energy-related data (6D), sustainability (7D), safety (8D), lean construction (9D) and possible industrialized construction (10D). The evaluation process was conducted using a case study. The case study included the development of a systemized procedure for the review and selection of design alternatives. The evaluation phase was conducted upon completing case study criteria and setting up platform to validate design alternatives.

The BIM-based automated VE approach for cost, schedule, and constructability reviews, aiding alternative material selection processes, is described in Figure 1. The flowchart presents the pathway for process review and material validation criteria. First, a 3D schematic model for the early design phase of the VE job plan was developed. The model presents an opportunity for the progress of these VE team meetings from the “Informational and Functional analysis” phase to the “Creativity and Evaluation” phase. The team further upgraded the model into a complete architectural model with building envelopes and created a structural model along with a mechanical, electrical, and plumbing (MEP) model, as illustrated in Figure 1. The process underscores the seamless interaction between the disciplines that conduct thorough constructability reviews and evaluations of the actual construction.

Case Study Building Project

The building for case study was a mixed-used Office and Laboratories building, named “Digital Futures building,” located in Cincinnati, OH. Its footprint was 180,000 SF which included a concrete parking garage, basement, and six-story steel structures. It also included 1,350 underground parking spaces with 26 surface lot spaces. This building presented an opportunity to apply the VE and BIM integration process from the preconstruction phase to the construction phase because of its magnitude and team involved in its construction. Figure 2 illustrates its structural floor plan and 3D view.

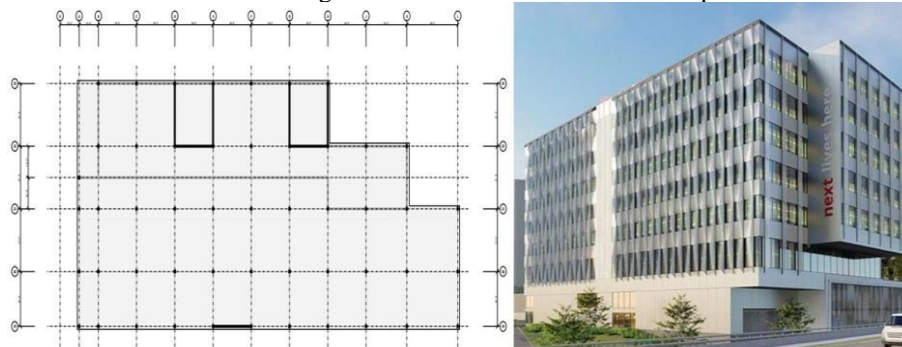


Figure 2. Typical structural floor plan and the 3D view of an ongoing “Digital Futures” project

Results and Discussion

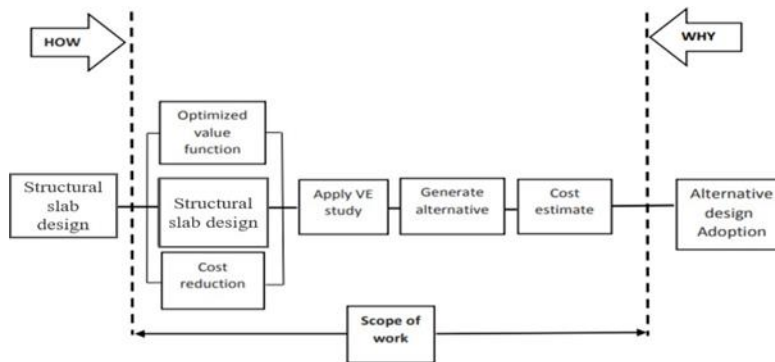
Integrated BIM and VE can enhance project value, schedule control and cost reduction. Based on the results of this study, an empirical approach to improve project value, reduce cost, enhance schedule overruns, and increase overall project quality is proposed. The approach is discussed in the job plan.

Value Engineering – Information Phase

First, all associated data required to develop the BIM model (shown in Figure 2) were collected, and the 3D model was generated based on partial 2D plans, layout design, and other vital construction data. The 3D model made visual deliberations easier and improved the project's early design, planning, and construction. Generating the 3D model helped synchronize the imaginary view of the VE team's involvement in the exercise to measure the ideas developed. The model further served as a reference point for both cost estimate (4D) and schedule (5D), as in Fig. 4 and 5. The 3D model aided the team to resolve constructability issues prior to construction. The information assured the use of VE and BIM integration process and ensured that the project objective was evaluated throughout the stages of construction. Additionally, the method provided a visual alignment of the original data to ensure that the project preserved the intended value for the owner and stakeholders.

Value Engineering – Function Analysis Phase

The functions of the project elements were identified in the chosen case study to assist in analyzing the VE generation of design alternatives. Functional analysis was crucial in achieving the primary purpose of creating design alternatives. The technique of analyzing the options for the VE study provided a tool for extensive participation in the design and cost optimization of the project. The generation of alternatives was based on defined analysis criteria. Additionally, the decisions of the team resulted from the capacity of the design to accommodate the actual implementation procedure and the flow of information. The proposed criteria for this study included in the building model were cost, schedule, quality, appearance, and energy efficiency. Figure 3 presents the FAST diagram. Figure 3. FAST diagram of the case study which shows the scope of the study.



Value Engineering – Creativity Phase

Creativity phase focused on generating alternatives. The BIM-based model served as a collaboration platform to assist VE team in visualizing and considering the merits and demerits of each alternative. Based on the FAST diagram, several alternatives were considered for further evaluation as in Table 1.

Table 1

Base Design and Alternatives	
Base Concrete Slab Design	Alternative Concrete Slab Design
Cast-in-place concrete with Joist Slab System	1. Flat Slab Structural System with Drops
	2. Band Beam Structural System
	3. Two-way Concrete Slab & Beam Structural System

Value Engineering – Evaluation Phase

The evaluation process aligned each considered alternative and subjected it to strict proof of the value equation. The value (owner requirement) is multiplied by the risk (i.e., performance per cost index, design appearance, and stability). Refer to equation 1:

$$\text{Equation 1: Value} = (\text{Performance} / \text{Cost}) \times \text{Risk}$$

In evaluating performance, attributes were determined to enable the scale to be measured and compared. Based on the equation, the higher the performance, the higher the value index generated;

same applies to risk. Different projects have different characteristics depending on the project goals. Table 2 lists the performance attributes of the case, and the scale was categorized into five stages.

Table 2

Performance Attributes		
Performance Attributes	Scale	Description
Project schedule/ Duration	5	Complete earlier more than by 4 weeks
	4	Complete earlier more than by 4 weeks or less
	3	Complete on Time
	2	Complete late by 4 weeks or less
	1	Complete late more than by 4 weeks.
Quality Index	5	Last 25 years or more
	4	Last 15 to 20 years
	3	Last 10 to 15 years
	2	Last 5 to 10 years
	1	Last 5 years or less

Table 3 presents the risk attributes of the project's suitability.

Table 3

Risk Attributes		
Risk Attributes	Scale	Description
Cost Index	5	\$35.98/SF
	4	\$45.50/SF
	3	\$66.80/SF
	2	\$79.00/SF
	1	\$86.00/SF
Appearance	5	Premium
	4	Attractive
	3	Moderate
	2	Unattractive
	1	Very Unattractive

Because cost optimization was one of the goals, one of the attributes was to consider cost risk for each alternative; appearance was selected as the second attribute because of the owners' special needs.

BIM Application on the Case Study Project

The 3D models of the case study building were created (refer to Figure 5) based on the BIM methodology. A series of alternative design and material selection analyses were defined to serve as a bedrock for the project database. The BIM model (Figures 4 and 5) generated cost data, including quantities, cost estimates, and construction schedules. The team executed model integration and clash

detection using Navisworks. The clash detection exercise aided in the smooth integration of various building components and systems, preventing unnecessary rework and waste during construction. The VE team resolved major constructability issues, leading to project time and cost reduction. Clash detection report showed 1805 clashes which were resolved before construction. The process used BIM capabilities to resolve the problems of material usage, handling, sequencing, scheduling, and cost issues. The BIM platform helped VE and other non-VE team members promptly exchange vital building information and data across all project phases.

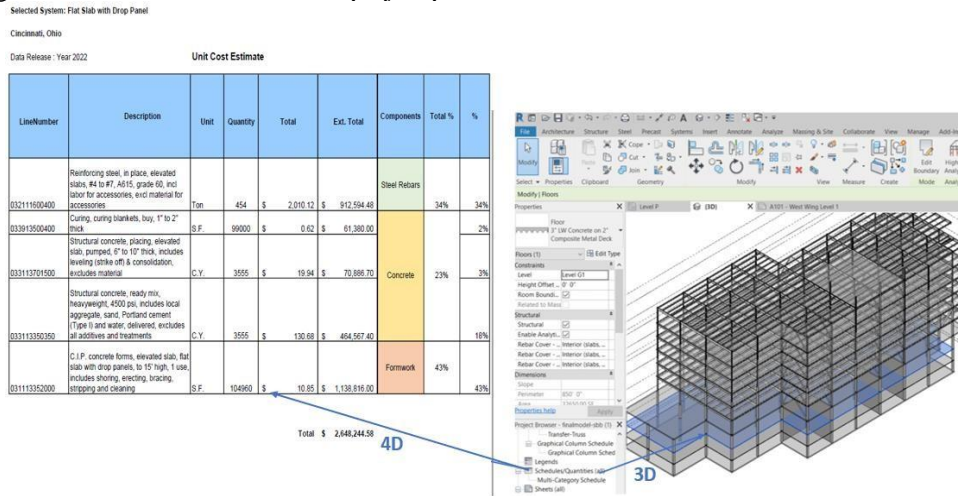


Figure 4. Transferring 3D - lightweight concrete floor on composite metal deck to 4D - Quantity takeoff and cost estimate

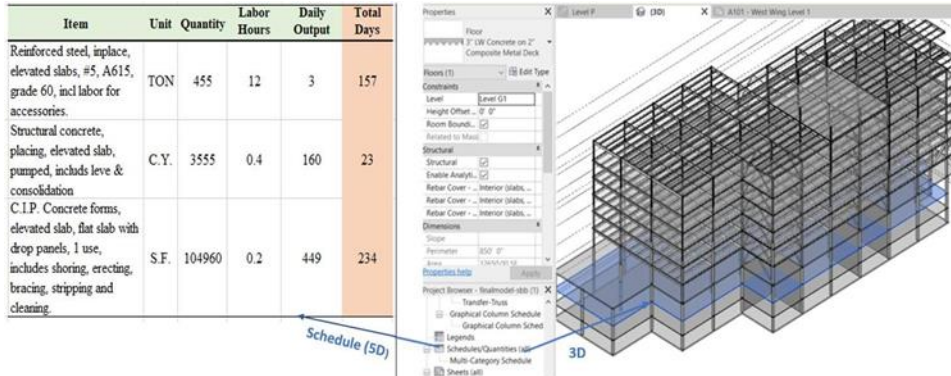


Figure 5. Converting 3D construction schedule to 5D

Conclusion

This study provided a framework for using BIM and VE applications to improve project value using a case study. Specifically, it examined the impact of using BIM with VE to improve information sharing and selecting appropriate design alternatives and decision-support models to assist the project team in evaluating identical design alternatives. This was to further the goal of Taher et al. (2019).

The research findings indicated that BIM and VE integration positively impacted projects and provided value to owners. The integration provided value to specific activities, such as team coordination, schedule control, cost control, quantity takeoff, estimation, and structural analysis which

goes beyond Taher et al. (2019) which was only limited to cost reduction on structural elements. This study contributes to the field of BIM and VE integration by developing a systemized framework to facilitate a smooth process of decision-making capabilities for industry stakeholders. This is a true benefit of improving construction costs, reducing conflicts, improving team communication, and reducing project duration which eliminates manipulation of individual project team members.

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