International Journal Of Health, Engineering And Technology (IJHET) *E-ISSN 2829 - 8683*
Volume 4, Number 6, March 2026, *Page. 1831 - 1845*
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Cost Savings In Workshop Building Structures Through Value Engineering Approach Based On Cold-Formed Steel With Integration Of Life Cycle Costing And Risk Evaluation

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Abstract

Workshop building structures commonly use conventional steel materials known for their strength, but they pose challenges in terms of cost, transportation, and time efficiency—particularly in projects located in remote areas. This study aims to optimize the structural cost of Workshop buildings by integrating the approaches of Value Engineering (VE), the selection of Cold-Formed Steel (CFS) material, the Life Cycle Costing (LCC) method, and risk evaluation. VE is applied to identify the primary functions of the structure and propose more efficient alternatives without compromising performance. CFS is selected due to its lightweight nature, ease of transportation and installation, and suitability for remote project locations. The LCC method is used to assess total costs over the building's life cycle, including initial investment, maintenance, and residual value. Risk evaluation is conducted to identify potential technical, operational, and economic obstacles that may affect implementation success. The results show that the use of CFS through VE and LCC approaches can significantly improve cost efficiency compared to conventional steel structures. This approach not only reduces initial project costs but also saves long-term expenses through minimal maintenance and optimal service life. Risk evaluation supports more informed decision-making, making this integrated approach an effective strategy for designing economical, efficient, and sustainable Workshop structures.

Keywords: Value Engineering, Cold-Formed Steel, Life Cycle Costing, Risk Evaluation, Cost Efficiency, Workshop Building Structure, Construction Optimization.

INTRODUCTION

In an increasingly competitive era of infrastructure development, cost efficiency has become a crucial indicator of the success of construction projects. In particular, the construction of workshop buildings faces the challenge of designing and implementing structures that are not only strong, functional, and safe, but also financially efficient within the limits of the available budget. Conventionally, Hot Rolled Steel (HRS) has been the dominant choice in steel structural design, based on its material strength characteristics and widespread use in the construction industry. However, this material has several significant limitations that affect cost aspects, especially in projects located in remote areas or regions with limited transportation access. Commonly identified issues include heavy material weight, the need for heavy equipment for mobilization, and high procurement and installation costs.

This phenomenon indicates fundamental problems in overall project cost optimization, both at the initial stage and throughout the building life cycle. At the micro level, individual projects—particularly workshop construction in hard-to-reach areas—often face inefficient cost structures due to the dominant use of materials that are less adaptive to site conditions. For example, procuring Hot Rolled Steel (HRS) in remote areas frequently requires substantial logistics costs, resulting in high total project costs. Construction projects in difficult locations may experience significant cost increases due to constraints in mobilizing heavy materials. At the meso level, the construction industry as a whole faces low project efficiency caused by conventional approaches that tend to ignore long-term cost savings (such as operation and maintenance costs) and the lack of integration between design and execution stages. At the macro level, these issues lead to increased national infrastructure investment costs, which may slow development in remote regions and ultimately reduce the competitiveness of the construction sector and limit regional economic potential. These cost optimization problems are further exacerbated by limited comprehensive historical data and planning methodologies that have not fully integrated functional value, total life cycle costs, and potential risks.

The causes of cost optimization problems and inefficiencies can be identified as follows, supported by previous studies. First, there remains a strong tendency to prioritize the lowest initial cost while neglecting potential savings in operational, maintenance, and end-of-life costs. Dell'Isola (1982), one of the pioneers of value engineering (VE), explicitly stated that a narrow focus on initial cost often results in suboptimal long-term decisions. This view is reinforced by Woodward (1997), who emphasized the importance of life cycle costing (LCC) to avoid long-term losses resulting from short-term savings. Second, there is a lack of integration between the design process and considerations of constructability and on-site logistics. Arditi and Gunaydin (1997) highlighted that minimal interdisciplinary integration in construction projects often triggers design changes during execution, delays, and ultimately cost overruns. Third, conventional cost estimation methods are often unable to accommodate the complexity of projects in special locations or the cost-saving potential of innovative materials such as Cold-Formed Steel (CFS), and they inadequately consider price volatility and risks affecting total costs. Flyvbjerg, Bruzelius, and Rothengatter (2003), through studies of mega-projects, showed that cost estimates are often "highly optimistic and inaccurate," partly due to insufficient consideration of risk and uncertainty. Fourth, structured risk analysis is minimal. Decision-making processes rarely involve systematic identification, evaluation, and mitigation of risks from the early stages of a project. Kerzner (2009) emphasized that failure to manage risk is a major cause of project failure, including cost-related aspects. In the context of new materials such as cold-formed steel (CFS), potential technical risks are often not well mapped in cost estimation, resulting in long-term savings that are not accurately quantified. Although cold-formed steel (CFS) offers significant cost-saving advantages, comprehensive understanding of optimal design, fabrication, and installation to maximize overall cost efficiency remains limited among practitioners. Consequently, the full potential of cold-formed steel (CFS) has not been fully utilized to achieve optimal cost performance.

Given these challenges, innovative solutions are needed that can inherently reduce costs without compromising structural quality and performance, particularly under conditions of limited budgets and complex logistics. In this context, Cold-Formed Steel (CFS), or light-gauge steel, becomes highly relevant. Cold-formed steel (CFS), which is formed at room temperature, offers significant advantages in weight efficiency, ease of prefabrication, and design flexibility—characteristics that are ideal for workshop building structures. The use of cold-formed steel (CFS) inherently reduces structural loads, accelerates on-site installation, and lowers logistics and labor costs compared to Hot Rolled Steel. This makes it a far more economical alternative to conventional steel, especially for projects in remote areas. The significance of cold-formed steel (CFS) lies in its ability to provide robust yet lightweight structural solutions while offering substantial cost-saving potential, making it well suited to addressing geographical constraints and budget limitations in workshop construction.

However, these issues indicate the need for an approach that not only suppresses costs but also anticipates implementation risks. In the application of Value Engineering (VE), analysis should not solely focus on balancing function and cost, but must also consider the uncertainties inherent in each design alternative and construction method. Decisions made without considering risk often result in unsustainable apparent efficiencies, as potential cost and schedule deviations emerge during the implementation stage. Therefore, risk evaluation becomes a crucial component of the VE process, serving to identify, assess, and anticipate potential technical, financial, and operational obstacles that may affect project performance. Integrating risk analysis into VE strengthens the basis for decision-making, ensuring that the selected alternatives not only provide the highest economic value but also demonstrate greater reliability and resilience against uncertainties throughout the workshop building life cycle.

To ensure that structural selection truly delivers optimal value through significant cost savings, this study proposes the development of a risk-based value engineering (VE) model integrated with life cycle costing (LCC) for cold-formed steel (CFS) to improve the cost performance of workshop building structures. This solution is designed to address the identified root causes. First, by integrating life cycle costing (LCC), the developed model enables comprehensive evaluation of all costs incurred over the building's service life, beyond initial costs alone, including operation, maintenance, and demolition costs. This approach leads to more sustainable and holistic cost-efficient decisions and identifies potential savings that are not visible in initial estimates. Second, the application of value engineering (VE) serves as a systematic method to identify the primary functions of workshop structures and evaluate various design alternatives, materials (particularly CFS), and construction methods that provide the best value in terms of cost, quality, and performance. As emphasized by Berawi, value engineering (VE) aims not only to reduce costs but also to ensure that function and quality are maintained. This approach enhances design integration and optimizes the use of life cycle costing (LCC) to achieve planned savings. Third, the integration of risk analysis allows for the identification, quantification, and mitigation of potential risks—technical, operational, environmental, and financial—arising from material selection and construction approaches. By proactively mapping risks, the model provides more accurate and realistic cost estimates and enables effective mitigation strategies to prevent unexpected cost escalation. This study specifically focuses on implementing value engineering (VE) and life cycle costing (LCC) in the use of cold-formed steel (CFS). Accordingly, the developed model can optimally leverage the intrinsic advantages of cold-formed steel (CFS)—light weight, prefabrication, and rapid installation—to reduce logistics, labor, and construction time costs. This results in workshop structures that are not only strong and functional, but also highly efficient and sustainable, particularly for projects in hard-to-reach locations, with significant overall cost-saving potential.

Thus, through the assessment of potential cost savings in workshop building structures via the application of value engineering (VE) based on the use of Cold-Formed Steel (CFS), fully integrated with life cycle costing (LCC) and risk analysis, this study is expected to produce structural alternatives that are more optimal, efficient, and sustainable, both technically and economically.

RESEARCH METHODS

Research Strategy

In addressing the research questions and testing the formulated hypotheses, a systematic process of data collection and analysis is required. According to Creswell (2012) in *Educational Research* (4th edition), the data collection process involves the appropriate selection of respondents and the gathering of information through techniques such as interviews and observations. Once the data have been obtained, the next stage is data analysis, which aims to process and organize the information into findings that can answer the research problems. This process is usually carried out by presenting data in the form of tables, graphs, or charts, as well as through in-depth narrative interpretation to draw conclusions and test the hypotheses.

The selection of a research strategy generally involves five main approaches, namely: experiments, surveys, archival analysis, historical studies, and case studies. Yin (1994) explains that the choice of research strategy is influenced by three main factors:

1. Research questions, or the type of questions posed (such as who, what, where, and how many, which tend to be more suitable for a survey approach);
2. The extent of the researcher's control over the object being studied; and
3. The focus on ongoing events, whether the study concerns contemporary events or past events.

The selection of an appropriate research strategy in this study is based on the type of research questions described in the previous subsection. Accordingly, the strategies employed in this research are case study and archival analysis.

Research Process

Identifying the research process is essential to ensure that the study is conducted effectively and efficiently and produces valid and relevant outcomes. According to Kumar (2011), the research process consists of three main phases:

1. The first phase involves identifying the research topic by defining the problem to be studied, which is crucial for developing an appropriate research design.
2. The second phase focuses on planning the study by formulating the research design to determine how answers to the research questions will be obtained.
3. The third phase is the development of research instruments used for data collection.

Based on the identified research strategy, this study employs benchmarking, survey methods, archival analysis, and case studies. Benchmarking, as defined by APQC (2024), is an approach used to measure internal processes and compare them with best-in-class practices. The survey method, according to Sugiyono (2018), is a quantitative approach used to collect data on beliefs, opinions, characteristics, behaviors, and relationships between variables through non-in-depth observations such as questionnaires or interviews. Archival analysis utilizes historical documents and records to support research findings and is recommended by Yin (2014) to be combined with case studies for deeper contextual understanding. A case study, as described by Yin (2009), is an empirical inquiry that investigates contemporary phenomena within real-life contexts, particularly suitable for “how” and “why” research questions.

This research focuses on workshop construction projects using cold-formed steel (CFS) with the integration of value engineering (VE), life cycle costing (LCC), and risk evaluation. The research questions (RQ1–RQ8) are summarized as follows:

1. RQ1 examines the implementation patterns of CFS-based workshop project management through a case study using descriptive analysis, questionnaires, and project archives.
2. RQ2 analyzes cost structures from planning to actual implementation using case studies and archival analysis to identify cost deviations.
3. RQ3 identifies construction stages and associated costs of CFS structures through surveys and archival project data.
4. RQ4 develops alternative designs, methods, and materials using value engineering to reduce costs without compromising quality, supported by comparative cost analysis between conventional steel (HRS) and CFS (case study).
5. RQ5 evaluates VE alternatives using a life cycle costing (LCC) approach to assess long-term cost efficiency, including initial, operational, maintenance, and end-of-life costs, discounted to present value and tested through sensitivity analysis (case study).
6. RQ6 identifies risks affecting VE–LCC integration through surveys and archival analysis of project risk and financial documents.
7. RQ7 develops an integrative model linking construction methods, VE, LCC, and risk to cost performance using Structural Equation Modeling (SEM) based on case study data.
   RQ8 synthesizes all findings to validate and operationalize a risk-based VE–LCC model through case studies, Delphi analysis, and validation questionnaires, producing practical guidelines and SOPs for CFS workshop projects.

RESULTS AND DISCUSSION

Implementation Method Patterns and Activities of Cold-Formed Steel (CFS) Structures in Workshop Projects

Findings

Based on the results of content validation and instrument clarity assessment by experts, as well as qualitative analysis of open-ended responses, several findings were identified regarding the patterns of implementation methods and activities of Cold-Formed Steel (CFS) structures in workshop projects.

1. The CFS construction implementation method is considered to comply with technical standards and field practices
   The majority of respondents agreed that the stages of CFS structural implementation followed clear and systematic technical procedures. This is indicated by the high level of agreement on indicators related to the suitability of work methods, installation sequences, and quality control during execution.
2. The CFS implementation method contributes significantly to project time efficiency
   The prefabrication system, lightweight structural weight, and the use of mechanical connections (bolts and self-drilling screws) accelerate the installation process compared to conventional steel structures. Respondents assessed that installation activities can be completed more quickly with lower dependence on heavy equipment.
3. CFS structural installation activities are relatively consistent with the project work plan
   Respondents stated that the discrepancy between planned implementation methods and field realization was relatively small. This indicates that the CFS implementation method has a higher level of certainty, particularly in workshop projects with repetitive structural configurations.
4. The selection of implementation methods directly affects project cost efficiency
   The CFS implementation method impacts not only time efficiency but also labor cost efficiency, equipment costs, and the reduction of material waste. Construction activities that are simpler and more modular are considered capable of reducing indirect project costs.

Discussion

Construction implementation methods play a key role in determining the effectiveness of applying Cold-Formed Steel (CFS) structures. The main characteristics of CFS, such as lightweight properties, fabrication precision, and modular systems, make the implementation method a strategic element that cannot be separated from project cost and time performance.

The time efficiency generated by the CFS implementation method aligns with the principles of construction industrialization, where most work is shifted to the fabrication stage, thereby reducing reliance on complex on-site activities. This condition is highly relevant for workshop projects in remote locations, where limitations in heavy equipment, skilled labor, and logistics access are major constraints.

Furthermore, the finding that implementation methods directly contribute to cost efficiency reinforces the argument that project cost control is determined not only by design or materials but also by construction execution strategies. Structured and precise work methods are able to minimize rework, material waste, and indirect costs resulting from project delays.

Implementation methods are not merely execution stages, but rather an initial foundation that influences the success of Value Engineering (VE) application, Life Cycle Costing (LCC) analysis, and risk management in subsequent research stages. These findings form the basis for discussing the relationship between implementation methods and cost performance as well as project value optimization.

Characteristics of Cost Planning and Cost Realization in Cold-Formed Steel (CFS)-Based Workshop Projects

Findings

Overall, cost management was assessed as effective. This study identified three main findings as the causes of cost deviations in CFS-based workshop projects, namely:

1. Inaccuracy of Initial Estimates
   Cost deviations primarily occurred when material quantity calculations were still based on conceptual drawings and were not supported by detailed shop drawings. This condition resulted in imprecise estimates of structural weight and the number of connectors.
2. Design Changes During Construction
   The highly precise and factory-fabricated CFS system has low flexibility for design changes. Design modifications during construction directly result in material waste and rework.
3. Idle Time Due to Field and Logistics Constraints
   Delays in material delivery and extreme weather conditions caused labor to become unproductive (idle), increasing labor costs without corresponding physical work progress.

The main sources of cost deviation do not originate from the CFS material itself, but rather from managerial aspects and initial project planning. Analysis of cost documents across three building scales (small, medium, and large) produced consistent findings that CFS structures are able to reduce structural weight by approximately ±30–38% compared to conventional steel. This weight reduction is directly proportional to:

- labor cost efficiency (±28–31%),
- material cost efficiency (±29–30%), and
- reduced deviation between the budget plan (RAB) and actual costs.

Another important finding is that the larger the scale of the workshop building, the more dominant the economic advantages of the CFS system become, particularly in terms of faster installation, minimal material waste, and stability of actual costs. Two main technical mechanisms were identified as enablers of cost efficiency in CFS projects, namely:

1. Reduction of Structural Tonnage
   The lighter structural weight increases labor productivity, reduces physical fatigue, and accelerates work duration.
2. Mechanical Connection Method (Zero Welding at Site)
   The use of self-drilling screws replaces on-site welding, thereby:
   - reducing the cost of skilled welding labor,
   - eliminating the risk of welding defects, and
   - improving the consistency of connection quality.

The combination of these two factors results in more controlled and predictable actual costs, even in large-scale projects.

Discussion

The cost advantages of the Cold-Formed Steel system are not derived solely from material prices, but primarily from the integration of the material’s technical characteristics and project cost management strategies. The main principle emerging from this discussion is “Slow Planning, Fast Execution.”

Meanwhile, the lightweight and prefabricated characteristics of CFS enable construction implementation that is fast, efficient, and minimizes waste on site. Thus, CFS is a structural system that is highly compatible for workshop projects in remote and high-risk locations, provided it is supported by integrated cost planning and strong project management discipline.

Implementation Methods and Activities of Cold-Formed Steel (CFS) Structures in Workshop Projects

Findings

Based on expert validation using the Delphi method and analysis of project documents from three workshop objects of different scales, this study found that the implementation method of Cold-Formed Steel (CFS) structures exhibits clear, consistent, and practically validated activity patterns. The main findings indicate that all experts agreed on four main phases of the CFS implementation method, namely:

1. planning and preparation,
2. on-site implementation activities,
3. cost and efficiency aspects, and
4. evaluation and standardization of methods.

All activities within these four phases were considered relevant and clearly described the construction process of CFS-based workshop projects. From the open-ended questions, it was found that on-site erection activities are the most dominant stage affecting project costs, particularly in projects with limited access. In addition, precision fabrication in the workshop and the accuracy of material delivery were identified as crucial factors determining smooth implementation and duration efficiency.

Quantitative findings from S-Curve analysis show that consistent application of the CFS system results in an acceleration of structural work duration by 21–27% compared to conventional steel systems, with the highest efficiency occurring during the installation phase (up to 44.44% in large-scale buildings). This acceleration directly impacts labor cost reduction of up to approximately ±30%. Furthermore, it was found that the lighter weight of CFS structures (±30–38%) provides significant advantages in logistics management, including optimization of container loading capacity, reduction in delivery frequency, and ease of loading and unloading at the project site.

Discussion

The results show that the efficiency of CFS structural implementation methods is not only caused by material characteristics, but primarily by a paradigm shift from heavy construction to assembly-based construction.

In the CFS system, most of the complexity of work is shifted to the pre-construction and off-site fabrication phases through precision cutting, CNC punching, and modular pre-assembly. This strategy significantly reduces dependence on heavy on-site work, which in conventional steel systems often becomes a source of delays and cost overruns.

The dominance of the erection phase as a cost determinant confirms that the elimination of welding and repainting work in the CFS system is a key factor in accelerating project duration. The use of mechanical connections (self-drilling screws and structural bolts) enables more stable installation progress, minimal weather disruption, and eliminates the need for complex weld joint inspections.

From a logistics perspective, findings related to remaining container load capacity indicate that CFS provides material distribution flexibility that is highly relevant for workshop projects in remote locations. This strengthens the argument that CFS efficiency is systemic, encompassing technical, time, cost, and supply chain management aspects simultaneously.

However, this study also emphasizes that the advantages of CFS implementation methods are highly dependent on early design finalization and shop drawings. Design changes during execution were proven to be the main source of efficiency degradation; therefore, method standardization and planning discipline are absolute prerequisites for the success of the CFS system. The implementation method of Cold-Formed Steel (CFS) structures has a more rational, controlled, and adaptive work pattern and is worthy of serving as an operational basis for developing SOPs for risk-based VE–LCC implementation in workshop projects.

Application of Value Engineering in CFS-Based Workshop Projects

Findings

Based on expert validation, questionnaires, open-ended questions, and empirical evaluation of three CFS-based workshop project objects, several main findings were obtained as follows:

1. The application of Value Engineering from the early planning stage is a key success factor. All experts stated that VE is most effective when applied during the early design phase, especially for workshop projects in remote locations with limited access and logistics.
2. Structural weight optimization is the main value creation mechanism. The application of VE in CFS systems consistently resulted in structural weight reductions of approximately ±22.98% to 38.52% compared to conventional steel, without reducing the main structural functions.
3. Cost and time efficiency are direct impacts of weight reduction and changes in work methods. Structural weight reduction directly correlates with:
4. labor cost reductions of up to ±58–68%,
5. implementation duration acceleration of approximately ±20–30%, and
6. reductions in logistics and material transportation costs.
7. Mechanical connection systems replace welding as the main VE innovation. The shift from welded connections to mechanical connections (self-drilling screws and structural bolts) was proven to reduce dependence on heavy equipment, welding inspections, and rework on site.
8. The benefits of VE become more significant in medium- to large-scale buildings. In projects with larger spans and floor areas, the economic advantages of the CFS system become increasingly dominant, particularly in terms of actual cost stability and schedule control.

Discussion

The application of Value Engineering in CFS-based workshop projects is not merely a cost-saving strategy, but an integrated value improvement approach involving design, materials, and implementation methods.

Function analysis using the Function Analysis System Technique (FAST) identified the primary structural function as “supporting design loads.” The analysis results indicate that conventional steel generates excess weight, allowing this function to be transferred to high-strength Cold-Formed Steel material (G550), which has a yield strength more than twice that of conventional steel. Thus, structural functions are still fulfilled with significantly smaller material volume and weight.

This material change triggers a positive domino effect on the overall project system. Weight reduction not only lowers material costs but also simplifies logistics, accelerates installation, reduces labor requirements, and improves occupational safety in remote locations. This explains why labor cost efficiency and project duration efficiency consistently show high values across the three case studies.

Nevertheless, the discussion also reveals technical limitations of CFS materials, such as the potential for local buckling and sensitivity to mechanical damage. Therefore, the success of VE is highly dependent on design accuracy, the use of stiffeners, and the integration of technical risk evaluation from the alternative evaluation stage.

Value Engineering in CFS-based workshop projects must be positioned as an integrated optimization cycle, not merely as the selection of low-cost materials. The integration of VE with mechanical implementation methods and advanced cost analysis forms a critical foundation for sustainable cost efficiency, particularly in projects with high access and logistics challenges.

Long-Term Cost Efficiency through the Integration of Value Engineering and Life Cycle Costing in CFS Workshop Projects

Findings

Based on Life Cycle Costing (LCC) analysis using Net Present Value (NPV), expert validation, and a review of quantitative and qualitative data, several key findings were obtained.

Cold-Formed Steel (CFS) G550 structures consistently demonstrated long-term economic advantages compared to conventional steel structures across all research objects. In the Tyre Repair building, the use of CFS resulted in life cycle cost efficiency of 8.11%; in the Tyre Shop, 5.89%; and in the 800 m² Warehouse, reaching 12.12%. These findings indicate that the larger the building scale, the more significant the economic benefits of LCC-based CFS application.

Maintenance cost components (OPEX) were identified as the main determining factor for differences in LCC values. CFS G550 structures were able to reduce maintenance costs by 60%–78% compared to conventional steel, primarily due to the elimination of periodic repainting requirements and the material's resistance to corrosion.

The analysis shows that conventional steel structures are more vulnerable to long-term cost inflation risks, particularly maintenance costs that increase significantly in the 20th to 25th years of service life. In contrast, the CFS system demonstrates better cost stability, thereby functioning as a mitigation mechanism for future cost risks.

Questionnaire results and open-ended responses indicate a high level of acceptance among practitioners and asset owners regarding the application of VE-based LCC, particularly due to ease of installation, time efficiency, and more predictable cost control in workshop projects located in remote areas.

Discussion

Decisions regarding structural system selection can no longer be based solely on initial costs, but must consider the total life cycle cost of the building. The integration of Value Engineering (VE) with Life Cycle Costing (LCC) has been proven to improve the quality of decision-making, as the technical efficiency generated by VE is validated from a long-term economic perspective.

The use of CFS G550 material, identified through the VE process as a solution to reduce excess structural weight, has direct implications for reducing logistics costs, accelerating implementation, and lowering maintenance burdens. When these VE outcomes are evaluated using NPV-based LCC, the resulting efficiencies are not only short-term but also sustainable throughout the building's service life.

The study results indicate that LCC serves as an important managerial justification tool. The presentation of LCC NPV data allows project owners and stakeholders to understand that an initial investment that is relatively similar or slightly higher for the CFS system can generate significant total savings in the long term. This is highly relevant for workshop projects in remote locations, where operational and logistics cost risks tend to be higher and more difficult to control.

Thus, the integration of VE and LCC is not merely a cost analysis method, but a strategic decision-making model capable of systematically linking technical efficiency, economic sustainability, and cost risk mitigation.

Risk Factors in the Integration of Value Engineering and Life Cycle Costing in Cold-Formed Steel Workshop Projects

Findings

Based on the analysis of expert and practitioner questionnaires, as well as the classification of risk levels using a probability and impact approach, this study identified a number of key risk factors that affect the success of integrating Value Engineering (VE) and Life Cycle Costing (LCC) in Cold-Formed Steel (CFS)-based workshop projects. The findings show that the most dominant risk factors originate not only from technical aspects, but also from contractual, organizational, financial, and regulatory aspects. These risks are grouped into several main categories as follows:

1. Contractual and Regulatory Risks
   It was found that project contracts generally still emphasize initial costs, without including obligations for life cycle cost analysis. The absence of national or international standards related to VE–LCC implementation further increases uncertainty in implementation and decision-making.
2. Competency and Methodological Risks

A lack of practitioner expertise in using LCC analysis tools, limited software availability, and the potential for technical errors in LCC calculations were identified as significant risks that may mislead VE recommendations. The selection of inappropriate discount rates was also found to be a factor with a major influence on design evaluation results.

3. Time and Planning Process Risks
   The integration of VE–LCC requires a longer planning period. Delays in LCC data collection and analyses conducted too late cause VE–LCC results to be suboptimal and difficult to implement during the construction phase.
4. Financial and External Risks
   Fluctuations in steel prices, inflation, exchange rates, energy costs, and geopolitical dynamics were identified as external factors that increase uncertainty in life cycle cost analysis. Financial risks were assessed as being more difficult to control than initial project costs.
5. Technical Risks of CFS Materials
   Uncertainty regarding the service life of CFS materials, limitations in joint performance data, and the lack of long-term maintenance data were identified as key technical risks affecting the accuracy of LCC analysis.
6. Organizational and Environmental Risks
   Organizational resistance arises when VE alternatives require higher initial investment. In addition, environmental factors such as carbon emissions and the impact of climate on long-term maintenance costs are still frequently overlooked. Integration with Life Cycle Assessment (LCA) was also found to be very limited.

Overall, the findings of RQ6 indicate that risks in VE–LCC integration in CFS workshop projects are multidimensional and interrelated, thus requiring systematic and structured mitigation approaches.

Discussion

The findings of RQ6 indicate that failure or ineffectiveness of VE–LCC integration is not caused by a single factor, but rather by a combination of structural and operational risks within the construction project management system. The dominance of contractual and regulatory risks indicates that construction procurement practices remain short-term oriented. When life cycle costs are not part of contractual requirements, LCC analysis results lack implementation power. This explains why VE–LCC often stops at the study stage without having a tangible impact on design decisions and project budgets.

Competency and methodological risks reinforce the finding that VE–LCC has not yet become a mainstream practice. A lack of understanding among stakeholders and practitioners causes analysis results to be perceived as complex, risky, or impractical. This condition triggers organizational resistance, especially when VE recommendations require higher initial investment even though they are more economical over the life cycle.

Time and planning process risks show that VE–LCC integration requires a shift in project management paradigms. Analyses conducted too late or data not being available on time cause VE–LCC to lose momentum in the decision-making process. This emphasizes the importance of integrating VE–LCC from the early stages of project planning.

Financial and external risks confirm that life cycle cost analysis is highly sensitive to macroeconomic and logistical conditions, particularly in workshop projects located in remote areas. Therefore, VE–LCC needs to be combined with risk management approaches that are adaptive to external uncertainties.

Technical risks related to CFS materials and environmental risks indicate that limitations in long-term technical data remain a major challenge. Without a strong database, LCC analysis may produce biased estimates. These findings reinforce the urgency of developing CFS material performance databases and integrating VE–LCC with sustainability approaches such as LCA.

Overall, risks in VE–LCC integration are systemic, meaning mitigation cannot be conducted partially. These findings and discussions provide a strong conceptual and empirical foundation for formulating risk-based VE–LCC SOPs in RQ8, so that dominant risks can be controlled preventively and in a structured manner.

Validation of the Conceptual Model of Relationships between Implementation Methods, Value Engineering, Life Cycle Costing, Risk, and Cost Savings

Findings

Based on data processing using the Structural Equation Modeling–Partial Least Squares (SEM-PLS) approach, this study produced causal relationships among variables affecting the cost performance of Cold-Formed Steel (CFS)-based workshop projects.

The structural model testing results show that all research hypotheses (H1 to H8) were accepted, as evidenced by T-statistics values greater than 1.96 and P-values less than 0.05 across all relationship paths among variables. These findings indicate that the relationships built in the conceptual model have strong and consistent statistical significance.

The Implementation Method (X1) was proven to be the most dominant exogenous variable in the model. This variable shows a very strong direct influence on Value Engineering (X2), risk-based Life Cycle Costing (X3), Risk Factors (X4), and directly on Project Cost Savings (Y). This demonstrates that the quality and accuracy of construction implementation methods serve as the starting point determining the success of the entire cost management system in CFS workshop projects.

Furthermore, Value Engineering (X2) was also proven to have a significant effect on risk-based Life Cycle Costing (X3) and Risk Factors (X4), as well as providing a direct effect on Cost Savings (Y). Although the magnitude of VE's direct effect on cost savings is not as large as that of Implementation Methods and LCC, these findings indicate that VE still plays an important role in the structure of inter-variable relationships.

Risk-based Life Cycle Costing (X3) shows a very strong influence on Cost Savings (Y) as well as on Risk Factors (X4). These findings confirm that a life cycle cost approach that considers risk is one of the main determining factors in achieving cost efficiency in CFS workshop projects.

Risk Factors (X4) were proven to have a significant effect on Project Cost Savings (Y). These findings indicate that technical, financial, time-related, organizational, and environmental risks have a real contribution to project cost realization and cannot be ignored in cost-related decision-making. The analysis also produced the following structural regression equations for the Cost Savings variable:

$X2 = 0.973\ X1 + \varepsilon_1$

$X3 = 0.960\ X1 + 0.253\ X2 + \varepsilon_2$

$X4 = 0.971\ X1 + 0.636\ X2 + 0.493\ X3 + \varepsilon_3$

$Y = 0.940\ X1 + 0.354\ X2 + 0.834\ X3 + 0.715\ X4 + \varepsilon_4$

The coefficient of determination (R^2) value of 0.951 indicates that 95.1% of the variation in Project Cost Savings can be explained by the combination of Implementation Methods, Value Engineering, risk-based Life Cycle Costing, and Risk Factors. This value reflects a very strong level of predictive accuracy of the model.

Discussion

The study results show that the Implementation Method (X1) acts as the most dominant exogenous variable in the risk-based VE–LCC integration model. The very strong direct influence of Implementation Methods on Value Engineering, LCC, Risk Factors, and Cost Savings confirms that in Cold-Formed Steel (CFS)-based workshop projects, the accuracy of work methods is the primary foundation for achieving cost efficiency. This aligns with the characteristics of the CFS system, which is highly dependent on installation precision, work sequencing, and logistical efficiency, especially in projects located in remote areas.

The role of Value Engineering (VE) in this model is strategic as an enabling variable. Although VE's direct effect on cost savings is relatively smaller than that of other variables, VE was proven to strengthen the effectiveness of LCC and risk management. These findings indicate that the main function of VE in CFS projects is not merely to generate instant cost savings, but to improve the quality of design and method decisions that impact long-term efficiency.

Risk-based Life Cycle Costing (LCC) emerges as the variable with the strongest direct influence on Cost Savings. This confirms that cost control in CFS workshop projects cannot rely solely on initial cost optimization, but must consider operational costs, maintenance costs, and long-term risks. Integrating risk into LCC analysis allows cost estimates to become more realistic and adaptive to field uncertainties.

Risk Factors (X4) show a positive influence coefficient on Cost Savings (Y). This finding does not imply that increasing risk increases costs, but rather indicates that active and structured risk management contributes to cost efficiency. The better technical, financial, environmental, and organizational risks are identified and controlled from the early stages, the greater the opportunity for projects to achieve cost-saving targets. In other words, risk in this model acts as a control variable, not as a passive source of loss.

The resulting statistical model proves that cost efficiency in CFS workshop projects is achieved through a layered mechanism, starting from appropriate implementation methods, optimized through Value Engineering, controlled through risk-based LCC analysis, and strengthened by systematic risk management. These findings provide strong scientific justification that risk-based VE–LCC integration is not only theoretically relevant, but also practically crucial in managing costs for light industrial buildings based on CFS.

Formulation of Risk-Based VE–LCC Standard Operating Procedures (SOPs)

Findings

Based on the synthesis of Research Question (RQ1–RQ7) results, descriptive statistical analysis of agreement levels and impact on cost performance, and validation of inter-variable relationships using the SEM-PLS method, this study produced a Standard Operating Procedure (SOP) for implementing risk-based Value Engineering–Life Cycle Costing in Cold-Formed Steel (CFS) workshop projects.

RQ8 shows that the formulated SOP is not conceptual in nature, but has been successfully translated into a systematic, structured, and applicable operational workflow that reflects actual field practices. This SOP explicitly covers six main stages, namely:

1. Establishment of construction implementation methods as the technical and cost baseline
2. Implementation of Value Engineering (VE) studies for function optimization and design alternatives
3. Net Present Value (NPV)-based Life Cycle Costing (LCC) analysis for life cycle cost evaluation
4. Identification and evaluation of technical, financial, organizational, and external risk factors
5. Integrated VE–LCC–Risk decision-making
6. Implementation, monitoring, and evaluation of project cost performance

The results of descriptive statistical analysis show that the key stages in this SOP obtained median and mode values ≥ 4, particularly in aspects of initial cost reduction through VE, reduction of material waste and time, organizational risk management, and achievement of project cost targets. This confirms that the structure of the formulated SOP is a direct reflection of practitioner consensus and empirical project experience.

As the main output of RQ8, this SOP was then visualized in the form of an integrated procedural flowchart, illustrating the sequence of stages, division of roles among project actors, and key decision points in the implementation of risk-based VE–LCC. This visualization is an integral part of the RQ8 findings as a form of operationalization of the research results.

Discussion

The formulation of a risk-based VE–LCC SOP represents a direct downstream application of the empirical findings of RQ1–RQ7 into an operational guideline that can be used by project practitioners. Unlike VE or LCC guidelines that are generally partial in nature, this SOP integrates technical, economic, and risk aspects simultaneously into a single, comprehensive decision-making flow.

The integration of risk-based Value Engineering and Life Cycle Costing stages within the SOP shows that design and implementation method decisions are no longer based solely on initial costs, but on life cycle cost evaluations that consider technical, financial, and organizational uncertainties. This is consistent with the results of RQ6 and RQ7, which show that risk factors—particularly organizational risks and stakeholder coordination—have a significant influence on project cost performance.

Visualization of the SOP in the form of a flowchart provides important added value in the discussion of RQ8. The SOP flowchart not only serves as a procedural communication tool, but also as a decision-support tool that helps practitioners understand cause–effect relationships among VE, LCC, and risk stages. With clear decision nodes, this SOP enables re-evaluation processes (feedback loops) when VE–LCC analysis results do not meet established cost and risk criteria.

In addition, the SOP structure based on a priority matrix (the result of integrating agreement and impact on cost) ensures that stages with the greatest influence on cost performance are positioned as core steps, while other stages function as system reinforcements and support. This approach makes the SOP more adaptive to resource limitations and project conditions in remote locations.

Conceptually and practically, the results of RQ8 strengthen this study's contribution by providing an evidence-based SOP that can be directly applied to Cold-Formed Steel workshop projects in Indonesia. With its applicative, structured, and empirically validated character, this risk-based VE–LCC SOP has the potential to be further developed as an institutional guideline or as an initial reference for national standards for light industrial buildings based on CFS.

CONCLUSION

Based on analyses addressing Research Questions RQ1–RQ8, this study comprehensively examines the relationships among construction execution methods, Value Engineering (VE), Life Cycle Costing (LCC), risk factors, and their implications for cost performance in Cold-Formed Steel (CFS) workshop projects. The key conclusions are as follows:

Construction execution methods are the fundamental driver of cost efficiency, directly enabling effective VE, accurate LCC, and robust risk control. The CFS structural system demonstrates significant economic advantages—especially for medium- to large-scale buildings—through weight reduction, faster installation, minimal material waste, and more stable actual costs compared to conventional steel. VE is effective in optimizing structural functions without compromising technical performance by reducing excess weight and selecting high-quality CFS materials. Risk-based LCC emerges as the primary determinant of long-term cost savings by evaluating life-cycle costs (CAPEX and OPEX) using a Net Present Value (NPV) approach, emphasizing that efficiency depends on costs across the building's lifespan rather than initial costs alone. Risk factors act as strategic decision-enhancing variables; proactive identification and management of technical, financial, organizational, and external risks strengthen cost efficiency rather than hinder it.

The integrated risk-based VE–LCC model is empirically validated using SEM-PLS, with all hypotheses (H1–H8) supported and an R^2 of 0.951 for cost savings, indicating strong explanatory power. As the study's main output, a practical, risk-based VE–LCC Standard Operating Procedure (SOP) is developed and operationalized, covering execution method definition, VE studies, NPV-based LCC analysis, risk identification and evaluation, integrated decision-making, and implementation with monitoring and evaluation. The SOP's flowchart visualization serves as a practical decision-support tool and has potential for institutional adoption or as a preliminary national reference for lightweight industrial CFS projects in Indonesia.

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