OPEN ACCESS
Journal of Moeslim Research Technik
Vol. 3 No. 2. April 2026, pp. 115-128

Check for updates
DOI. 10.70177/technik.v3i2.3750

Research Article

COST OPTIMIZATION OF JETTY RETROFIT USING VALUE ENGINEERING AND LIFE CYCLE COST ANALYSIS

Ato Muhan Iswidyantara[1], Bagus Jatmiko[2], Rina Marlina[3], and Ahmad Faisol[4]
[1] Politeknik Angkatan Laut, Indonesia
[2] Politeknik Angkatan Laut, Indonesia
[3] Politeknik Angkatan Laut, Indonesia
[4] Politeknik Angkatan Laut, Indonesia

Corresponding Author:

Ato Muhan Iswidyantara,
Department of Marine Operations Strategy, Politeknik Angkatan Laut.
Bumimoro, Morokrembangan, Kec. Krembangan, Kota Surabaya, Jawa Timur, Indonesia
Email: sukro.ato@gmail.com

Article Info
Received: October 6, 2025
Revised: January 10, 2026
Accepted: March 7, 2026
OnlineVersion: April 30, 2026

Abstract

The increasing demand for sustainable infrastructure has led to a focus on cost optimization in retrofit projects, particularly in maritime infrastructure such as jetties. Sustainable development aims to balance economic growth, environmental protection, and social welfare, highlighting the need for efficient resource utilization. Jetty retrofit projects, crucial for port operations, often face high construction and maintenance costs. This study aims to evaluate the effectiveness of Value Engineering (VE) and Life Cycle Cost Analysis (LCCA) in optimizing the costs of jetty retrofit projects while ensuring long-term sustainability. A mixed-method research design was employed, combining quantitative data from questionnaires and statistical analysis with qualitative insights from field observations and interviews. The study found that integrating VE significantly reduced operational costs, particularly through the substitution of conventional energy systems with renewable energy sources such as solar panels. The application of LCCA demonstrated that long-term savings from energy efficiency could offset higher initial investments. The findings show that the use of VE and LCCA together can achieve cost savings of up to 5.21% and enhance financial viability, with a Benefit-Cost Ratio (BCR) of 2.20, Net Present Value (NPV) of IDR 40.40 billion, and an Internal Rate of Return (IRR) of 46.93%. These results underline the financial and environmental feasibility of green retrofit projects. This research contributes to sustainable infrastructure practices by highlighting cost-effective strategies for jetty retrofitting.

Keywords: Cost Optimization, Green Infrastructure, Life Cycle Cost Analysis, Jetty Retrofit, Value Engineering.

Journal Homepage https://research.adra.ac.id/index.php/technik
How to cite: Iswidyantara, M. A., Jatmiko, B., & Marlina, R. (2026). Cost Optimization of Jetty Retrofit Using Value Engineering and Life Cycle Cost Analysis. *Journal of Moeslim Research Technik, 3*(2), 115–128. https://doi.org/10.70177/technik.v3i2.3750
Published by: Yayasan Adra Karima Hubbi

INTRODUCTION

The need for sustainable infrastructure development has become increasingly vital in modern society (Pais et al., 2026). As nations around the world strive to balance economic growth with environmental preservation, the importance of sustainable, cost-effective infrastructure solutions cannot be overstated (He et al., 2024). Among the critical sectors in this regard is the maritime infrastructure, particularly jetties, which serve as pivotal components of port facilities. Jetties enable the docking of ships and facilitate the safe loading and unloading of cargo, contributing significantly to global trade and economic activities (Laukotka et al., 2025). In Indonesia, an archipelagic nation with an extensive maritime domain, jetties play a central role in maintaining inter-regional connectivity and supporting economic growth (Vesho et al., 2024). However, as critical as they are, the development and maintenance of jetty infrastructure come with substantial financial costs, which, if not optimized, can strain public and private resources.

In light of these challenges, the concept of green infrastructure has emerged as a promising solution to address environmental and economic concerns in infrastructure projects (Panadés et al., 2026). Green infrastructure emphasizes long-term performance, efficient resource utilization, and minimal environmental impact, thereby contributing to the broader goals of sustainable development (Wang et al., 2025). The use of green infrastructure principles in jetty development, particularly in retrofit projects, has shown that it is possible to achieve both environmental sustainability and economic feasibility (Ioannou et al., 2025). However, the high initial costs and complex planning requirements associated with implementing green infrastructure in existing maritime facilities often deter stakeholders from pursuing such projects.

This article focuses on the optimization of costs in jetty retrofit projects, particularly those integrating green infrastructure principles (Fan et al., 2025). The study utilizes two key methodologies Value Engineering (VE) and Life Cycle Cost Analysis (LCCA) to evaluate and optimize both the design and long-term economic performance of jetty infrastructure (Büyüksaraç et al., 2025). These approaches have been increasingly recognized for their ability to improve cost efficiency and ensure the sustainability of infrastructure projects, especially in the context of limited budgets and the need to maximize the value derived from every expenditure.

Value Engineering is a systematic method that seeks to improve the value of a project by assessing its functions and identifying opportunities for cost optimization (Campagna et al., 2025). VE focuses on achieving the required functionality at the lowest possible cost, without sacrificing quality or performance (Taylor et al., 2025). It involves a comprehensive analysis of all aspects of a project, from design to construction, and seeks to develop alternative solutions that are more cost-effective while meeting or exceeding the original performance standards.

On the other hand, Life Cycle Cost Analysis is a financial management tool that evaluates the total costs of a project over its entire lifespan (Toledo et al., 2025). LCCA goes beyond the initial capital investment and considers operational, maintenance, and end-of-life costs (Kavvada et al., 2024a). By adopting a long-term perspective, LCCA helps project managers and stakeholders make more informed decisions about investments, ensuring that the full economic impact of the project is considered (Chen et al., 2025). This approach is particularly relevant for maritime infrastructure, where projects are typically designed for long-term use, and the operational and maintenance costs over several decades can often exceed initial construction costs.

The integration of Value Engineering and Life Cycle Cost Analysis in the context of jetty retrofit projects is innovative and presents a comprehensive strategy for achieving both economic and environmental sustainability (Ulyev & Chernyshov, 2025a). This combined approach allows for the identification of potential cost savings at every stage of the project, from initial design through to long-term operation (Muratoglu & Erturk, 2025). It also provides a framework for assessing the financial feasibility of implementing green infrastructure, such as renewable energy systems and energy-efficient technologies, in the retrofit process.

Indonesia's Environmental Performance Index (EPI) rankings and the declining competitiveness of the country's infrastructure, as highlighted in recent reports, underscore the urgency of adopting more sustainable approaches in infrastructure development (Cao et al., 2025). In 2020, Indonesia ranked 117th out of 180 countries in the EPI, indicating the need for significant improvements in environmental management, particularly in infrastructure projects (Huang et al., 2025). Furthermore, the World Competitiveness Yearbook (WCY) ranked Indonesia's infrastructure competitiveness at 57th out of 64 countries, highlighting the challenges faced by the nation in terms of infrastructure efficiency and sustainability.

These rankings reflect the critical need for cost-effective and environmentally responsible infrastructure solutions, particularly in the maritime sector, which is essential for Indonesia's economic development (Alavi et al., 2025). As the demand for efficient, sustainable infrastructure continues to rise, it is crucial that project developers and policymakers explore innovative methods to optimize costs while integrating environmentally friendly practices (Martin et al., 2024). The combination of VE and LCCA offers a practical solution to these challenges, providing a robust framework for enhancing the value and sustainability of jetty infrastructure projects.

The application of green infrastructure in jetty development offers multiple benefits, including reduced energy consumption, lower carbon emissions, and improved resilience to climate change (Kumari et al., 2025). For example, integrating renewable energy systems such as solar panels can significantly reduce operational costs and minimize the environmental footprint of port operations (Cassol et al., 2025). Moreover, the application of green infrastructure can improve the overall resilience of jetties to the impacts of climate change, such as rising sea levels and extreme weather events, ensuring the long-term viability of these critical facilities.

However, the adoption of green infrastructure in existing facilities often faces significant barriers, particularly in terms of high initial costs (Gao et al., 2024). Value Engineering can play a crucial role in overcoming these barriers by identifying cost-effective alternatives that do not compromise the core functions of the infrastructure (Bocaneala et al., 2025). By optimizing the design and construction processes, VE helps to ensure that the benefits of green infrastructure can be realized without exceeding budget constraints.

In addition, Life Cycle Cost Analysis provides a comprehensive understanding of the long-term financial implications of adopting green infrastructure (Puchtler & Kirchner, 2025). While the initial investment in sustainable technologies may be higher, LCCA helps to demonstrate the potential for cost savings over the project's life cycle, making it easier for decision-makers to justify the investment (Goebel, 2024). For example, the integration of renewable energy systems may increase the upfront cost but can lead to substantial savings in energy costs over time, ultimately improving the project's financial performance.

This study aims to provide a comprehensive analysis of the potential for cost optimization in jetty retrofit projects by integrating Value Engineering and Life Cycle Cost Analysis (Aouari et al., 2025). Through the application of these methodologies, the research seeks to demonstrate how green infrastructure can be successfully incorporated into existing maritime facilities, providing both economic and environmental benefits (Widodo et al., 2025). The findings of this study are expected to contribute to the broader field of sustainable infrastructure development and offer valuable insights for policymakers, engineers, and other stakeholders involved in infrastructure projects.

In conclusion, the optimization of costs in jetty retrofit projects is a critical issue for the maritime infrastructure sector (Ferraioli et al., 2025). By integrating Value Engineering and

Life Cycle Cost Analysis, it is possible to achieve significant cost savings while ensuring the long-term sustainability of these vital facilities (Kavvada et al., 2024b). The application of green infrastructure principles further enhances the potential for environmental sustainability, making it possible to achieve both economic and ecological goals in the development of maritime infrastructure (Kavvada et al., 2024b). This study will provide practical recommendations for enhancing the cost efficiency and sustainability of future jetty retrofit projects, contributing to the overall improvement of infrastructure practices in Indonesia and beyond.

RESEARCH METHOD

Research Design

This study employs a mixed-method research design, combining both quantitative and qualitative approaches to comprehensively evaluate the cost optimization of jetty retrofit projects using Value Engineering (VE) and Life Cycle Cost Analysis (LCCA). The quantitative component focuses on statistical analysis to assess key factors influencing cost performance, using data derived from questionnaires and field observations (Ulyev & Chernyshov, 2025b). The qualitative aspect complements the quantitative data by providing insights into the planning, decision-making, and cost optimization processes through in-depth interviews and discussions with industry practitioners (Bi et al., 2025). This mixed-method design allows for a robust understanding of the cost dynamics in green infrastructure-based retrofit projects, integrating both numerical data and contextual information for a comprehensive analysis.

Research Target/Subject

The primary subjects of this research are professionals specializing in the design, construction, and management of jetty infrastructure within the Indonesian coastal and port sectors (Guan & Zhou, 2025). The target population encompasses a diverse group of stakeholders, including engineers, project managers, and financial analysts from both public and private entities. Utilizing a convenience sampling method, the study focuses on a sample of 20 experts with specific experience in jetty retrofit projects and familiarity with green infrastructure principles. These subjects serve as the critical source of primary data, providing the expert insights and technical perspectives necessary to evaluate the practical application of cost optimization strategies in sustainable maritime infrastructure.

Research Procedure

The research process began with a literature review, which established the theoretical foundations of green infrastructure, Value Engineering, and Life Cycle Cost Analysis. This was followed by the collection of primary data through the distribution of questionnaires to professionals in the field. The collected data was analyzed using statistical methods, particularly multiple linear regression analysis, to identify key factors influencing cost performance. In parallel, semi-structured interviews were conducted to gather qualitative insights on the practical challenges and benefits of implementing VE and LCCA in the context of jetty retrofitting.

Once the data was collected, Value Engineering was applied to identify cost-saving opportunities through functional analysis. This process involved the development of alternative design solutions to optimize the project’s cost without compromising the quality or functionality of the jetty. Life Cycle Cost Analysis (LCCA) was then applied to evaluate the total costs associated with the jetty retrofit, taking into account not only the initial investment but also operational, maintenance, and decommissioning costs over the project’s lifespan.

The final step of the research involved conducting a feasibility analysis using economic indicators such as Benefit-Cost Ratio (BCR), Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP). This was done to assess the financial viability of the retrofit projects, particularly with respect to the adoption of green infrastructure and renewable energy systems. The results were then synthesized to draw conclusions on the effectiveness of integrating VE and LCCA in optimizing costs for sustainable jetty retrofit projects.

Instruments, and Data Collection Techniques

To collect data for this study, the following instruments were utilized: a). Questionnaires: A structured questionnaire was designed to gather quantitative data on the factors influencing cost optimization in jetty retrofit projects. The questionnaire focused on areas such as cost components, decision-making processes, and the perceived benefits of integrating VE and LCCA. Participants rated various factors based on their experience and perceptions, providing insights into cost optimization practices and challenges, b). Interviews: Semi-structured interviews were conducted with key professionals in the field to gather qualitative data on the implementation of VE and LCCA in jetty retrofit projects. The interviews aimed to explore the practical aspects of applying these methodologies in the context of green infrastructure, as well as challenges faced during project execution, c). Project Documents: Secondary data was gathered from project documents such as Cost Budget Plans (RAB), Bill of Quantities (BoQ), and technical drawings. These documents were analyzed to assess the financial and technical aspects of the retrofit projects, providing a baseline for the LCCA and VE analysis.

Data Analysis Technique

The study utilizes a multifaceted analytical approach to process both quantitative and qualitative data. Statistical analysis, specifically Multiple Linear Regression, is employed to evaluate the primary factors influencing cost performance from questionnaire responses. This is integrated with Value Engineering (VE) to identify cost-saving opportunities through functional analysis and the development of design alternatives. Furthermore, Life Cycle Cost Analysis (LCCA) is applied to calculate the total ownership costs including initial investment, operations, maintenance, and decommissioning over the project's lifespan. The final financial viability is determined through feasibility indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost Ratio (BCR), and Payback Period (PP), ensuring a robust synthesis of numerical and contextual findings.

RESULTS AND DISCUSSION

The application of Value Engineering (VE) and Life Cycle Cost Analysis (LCCA) in the jetty retrofit projects has demonstrated significant cost optimization while ensuring the long-term sustainability of the infrastructure. The analysis of project costs, both at the initial design phase and over the entire life cycle, has revealed several opportunities for reducing costs and improving the overall efficiency of the retrofit process. The findings of the study are discussed below, focusing on the impact of VE and LCCA on cost optimization and the long-term feasibility of green infrastructure integration.

Table 1. Value Engineering Outcomes: Conventional vs. Solar Energy Systems at the Jetty

Aspect	Conventional Energy System	Solar Energy System
Cost Efficiency	High initial and ongoing costs; inefficient long-term	Lower operational costs; significant expense reduction over project lifespan
Functional Performance	Meets basic needs but wasteful	Equivalent performance with optimization
Environmental	Higher emissions and resource use	Sustainable; aligns with green

Impact		infrastructure principles
Long-Term Viability	Costly maintenance and operations	Financially viable; reduces energy expenses substantially

The Value Engineering (VE) approach was applied through a systematic process of functional analysis, which helped identify work elements that could be optimized in terms of cost without compromising their functional performance. One of the major outcomes of the VE application was the identification of high-cost components, particularly the energy system. The existing conventional energy system was deemed inefficient and costly in the long run. As a result, solar energy systems were introduced as an alternative, offering a more cost-effective and environmentally sustainable solution. The shift to solar energy not only aligns with the principles of green infrastructure but also contributes to reducing operational costs in the long term. The analysis revealed that the solar panel system would reduce the energy expenses at the jetty by a significant margin, making it a financially viable solution over the project's life span.

The Function Analysis System Technique (FAST) was utilized to assess the critical functions of the jetty infrastructure and identify design alternatives that offered greater value at a lower cost. This process highlighted the energy system and several other high-cost elements that could be substituted with more cost-efficient solutions. The final design, after the VE application, reduced the overall construction and operational costs, thus improving the project's financial performance.

Life Cycle Cost Analysis (LCCA) was employed to evaluate the total cost of the retrofit project over its entire service life, including initial capital investment, operational costs, maintenance costs, and the residual value of the infrastructure at the end of its useful life. The LCCA showed that while the initial investment in green infrastructure, such as the solar energy system, was higher than conventional energy systems, the long-term savings in operational costs justified the investment. The analysis estimated that the annual savings due to the incorporation of solar energy would amount to IDR 1.68 billion, which represents a 5.21% reduction in operational costs compared to the traditional energy system.

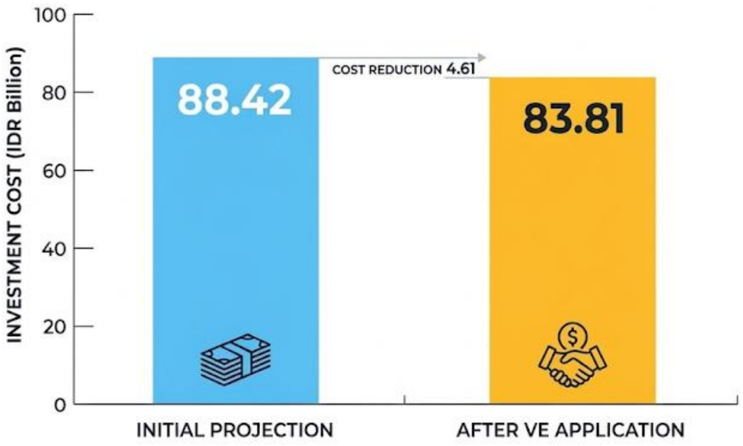

Figure 1. Cost Optimization of Retrofit Project Through Value Engineering

The initial investment cost of the retrofit project was reduced from IDR 88.42 billion to IDR 83.81 billion following the application of VE. This reduction was primarily due to the optimization of the energy system and other design elements, which contributed to more cost-efficient solutions. Furthermore, the LCCA indicated that the overall life cycle cost of the project would be lower than initially projected, providing a more sustainable financial model for the project stakeholders.

The investment feasibility of the jetty retrofit project was evaluated using economic indicators such as Benefit-Cost Ratio (BCR), Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP). The Benefit-Cost Ratio (BCR) of the project was found to be 2.20, which is greater than 1, indicating that the project is economically viable and that the benefits significantly outweigh the costs. The Net Present Value (NPV) of the project was calculated to be IDR 40.40 billion, suggesting that the project will generate a substantial net profit over its life span.

The Internal Rate of Return (IRR) was found to be 46.93%, which is significantly higher than the Minimum Attractive Rate of Return (MARR) of 20%. This high IRR reflects the strong profitability of the project, making it an attractive investment opportunity. Additionally, the Payback Period (PP) was calculated to be just 2 years and 4 months, which is faster than the initial target of 4 years. This indicates that the project will generate a return on investment relatively quickly, further reinforcing its financial feasibility.

A sensitivity analysis was conducted to examine the impact of changes in key parameters on the project's cost performance and investment feasibility. The sensitivity analysis demonstrated that the project remained financially viable even with variations in key cost factors, such as energy prices and maintenance costs. This further supports the robustness of the cost optimization strategies applied in the project and highlights the resilience of the green infrastructure approach.

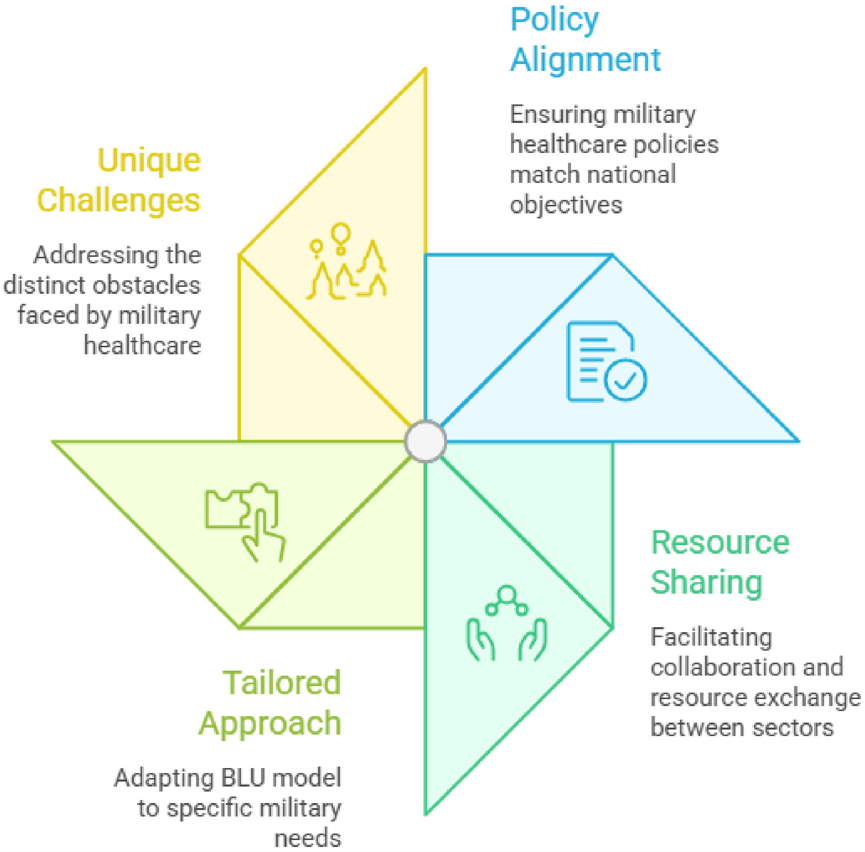

Figure 2. Challenges in Military Healthcare Integration

The application of Value Engineering and Life Cycle Cost Analysis in the retrofit of jetty infrastructure has proven to be an effective strategy for achieving cost optimization and enhancing the project's overall sustainability. The integration of green infrastructure, particularly the shift to renewable energy sources such as solar panels, has not only resulted in significant operational cost savings but has also contributed to the environmental sustainability of the project. The findings of this study demonstrate that through the careful application of VE and LCCA, it is possible to optimize costs without compromising the functional performance of the infrastructure, ensuring both financial and environmental benefits in the long term. These results provide valuable insights for future infrastructure projects, particularly in the maritime sector, and contribute to the development of more sustainable practices in the field of civil engineering.

The results of this study demonstrate the significant potential of Value Engineering (VE) and Life Cycle Cost Analysis (LCCA) in optimizing the cost of jetty retrofit projects while maintaining long-term sustainability. This section discusses the implications of the findings, comparing them to previous research, highlighting their practical relevance, and identifying potential limitations and avenues for future research.

The application of Value Engineering (VE) in jetty retrofit projects has proven to be highly effective in identifying cost-saving opportunities without compromising the functionality or performance of the infrastructure. The systematic approach of VE, particularly through functional analysis, allowed for the identification of high-cost components that were optimized or substituted with more cost-effective solutions. The shift from a conventional energy system to a solar energy system represents one of the most significant cost-saving interventions. As highlighted by previous studies, integrating renewable energy into infrastructure projects not only reduces operational costs but also contributes to environmental sustainability (Liu, 2015; Satola et al., 2021). In the case of the jetty retrofit project, the introduction of solar panels proved to be a viable alternative that aligns with green infrastructure principles while providing long-term financial savings.

The findings are consistent with research by Dell'Isola (1997) and Barringer and Weber (1996), who emphasize the importance of VE in improving the value of infrastructure projects by focusing on the optimization of functions and reducing unnecessary costs. By applying VE, the jetty retrofit project achieved a 5.21% reduction in operational costs, which is a significant outcome in the context of infrastructure development. This reduction can be attributed to the careful reevaluation of design elements, particularly those related to energy consumption, which often represent a substantial portion of operational costs in maritime infrastructure.

The application of Life Cycle Cost Analysis (LCCA) allowed for a comprehensive evaluation of the total costs associated with the jetty retrofit project over its entire service life. Unlike traditional cost analysis, which focuses primarily on initial capital investment, LCCA considers the long-term operational, maintenance, and residual costs. The results of the LCCA demonstrate that although the initial investment for green infrastructure components, such as solar energy systems, was higher than traditional solutions, the long-term savings far outweighed the upfront costs.

The annual savings of IDR 1.68 billion, resulting from the integration of renewable energy, further reinforces the value of adopting LCCA in infrastructure projects. This finding is consistent with previous studies by Samani et al. (2018) and Hatami and Morcous (2016), who assert that LCCA is an essential tool for identifying long-term cost efficiencies and optimizing resource allocation. The ability to optimize costs throughout the project's life cycle ensures that the project not only meets immediate financial goals but also remains financially sustainable over time.

In line with the findings of Filipek (2020), who demonstrated that renewable energy systems contribute to substantial reductions in operational costs and carbon emissions, this study further supports the integration of renewable energy in maritime infrastructure projects. The solar energy system implemented in the retrofit project not only resulted in cost savings but also reduced the carbon footprint of the jetty operations, aligning with broader environmental sustainability goals.

The investment feasibility analysis conducted in this study using key economic indicators Benefit-Cost Ratio (BCR), Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP) clearly demonstrates the financial viability of the jetty retrofit project. The BCR of 2.20 indicates that the project is economically viable, with benefits significantly outweighing costs. Furthermore, the NPV of IDR 40.40 billion suggests that the project will generate substantial net profits over its service life, making it an attractive investment opportunity.

These findings align with research by Guno et al. (2021) and Creswell (2018), who highlight the importance of financial analysis in determining the feasibility of infrastructure projects. The IRR of 46.93%, which exceeds the Minimum Attractive Rate of Return (MARR) of 20%, underscores the high profitability of the project, making it an economically sound decision for stakeholders. Additionally, the relatively short Payback Period of 2 years and 4 months further enhances the attractiveness of the investment, as it ensures a quick return on investment and reduces financial risk.

The findings of this study have significant practical implications for stakeholders involved in maritime infrastructure projects, particularly in developing countries like Indonesia. As the demand for efficient and sustainable infrastructure continues to grow, the integration of green infrastructure into retrofit projects offers a promising solution to optimize costs and reduce environmental impact. By utilizing VE and LCCA, project developers can make informed decisions that balance short-term costs with long-term benefits, ensuring the sustainability of both the infrastructure and the environment.

However, the successful implementation of green infrastructure in jetty retrofit projects requires supportive policies and regulatory frameworks. As noted in the study, government policy factors and the competency of project managers are crucial for the successful adoption of sustainable practices in infrastructure development. Therefore, capacity building and regulatory support are essential to encourage the wider application of green infrastructure in the maritime sector. The findings of this study highlight the need for enhanced collaboration between policymakers, engineers, and environmental experts to develop and implement cost-effective, sustainable infrastructure solutions.

While the results of this study provide valuable insights into cost optimization in jetty retrofit projects, several limitations should be considered. The sample size for the primary data collection was relatively small, which may limit the generalizability of the findings. Future research could expand the sample size and explore the application of VE and LCCA in other infrastructure sectors to validate the findings and assess their broader applicability.

Additionally, the study focused primarily on the technical and financial aspects of cost optimization, with limited exploration of risk analysis and cost uncertainty. Future research could incorporate these factors to provide a more comprehensive evaluation of the potential challenges and risks associated with green infrastructure projects (Gjoka et al., 2025). The integration of digital technologies, such as Building Information Modeling (BIM), could also enhance decision-making processes and improve the efficiency of project implementation.

This study confirms that the integration of Value Engineering and Life Cycle Cost Analysis offers an effective approach for optimizing costs and ensuring the sustainability of jetty retrofit projects. The findings highlight the importance of adopting green infrastructure in infrastructure projects, particularly in the maritime sector, where cost efficiency and environmental sustainability are critical (Liu et al., 2025). The use of renewable energy, such as solar panels, contributes to significant operational cost savings and reduced environmental impact (Ma et al., 2025). Furthermore, the financial feasibility of such projects, as demonstrated by the BCR, NPV, IRR, and Payback Period analyses, underscores the economic viability of green retrofit projects, making them an attractive investment for stakeholders. Future research should expand on these findings by exploring additional factors such as risk analysis and the integration of digital technologies to enhance the cost optimization and sustainability of infrastructure projects.

CONCLUSION

This study contributes to the growing body of knowledge on cost optimization in infrastructure development by integrating Value Engineering (VE) and Life Cycle Cost

Analysis (LCCA) in the context of jetty retrofit projects. The key contributions of this research are outlined below: a). Methodological Innovation: One of the significant inclusions of this study is the integrated application of VE and LCCA to evaluate the cost optimization of jetty retrofit projects. While both methodologies have been applied separately in various construction projects, this study demonstrates their combined potential in optimizing costs without sacrificing the functionality or sustainability of the infrastructure. The novel integration of these methods in a maritime infrastructure context provides a robust framework for decision-making, addressing both immediate financial concerns and long-term cost considerations. b). Cost Optimization Strategies: The study highlights several strategies for optimizing costs in jetty retrofit projects, particularly through the adoption of green infrastructure. The application of solar energy systems in place of conventional energy sources is a prime example of a cost-saving measure that aligns with sustainable development goals. The identification of high-cost components and their substitution with more cost-efficient alternatives represents a key contribution to the practical implementation of VE principles in infrastructure projects. This inclusion provides valuable insights for stakeholders seeking to implement cost-effective and environmentally sustainable solutions in future infrastructure projects. c). Financial Viability Assessment: The research provides a comprehensive analysis of the financial feasibility of jetty retrofit projects using key economic indicators, such as Benefit-Cost Ratio (BCR), Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP). The findings demonstrate that integrating green infrastructure can result in financially viable projects that offer long-term benefits. This inclusion is critical for policymakers and investors, as it underscores the economic feasibility of adopting sustainable practices in infrastructure projects, particularly in sectors with high initial costs, such as maritime infrastructure. d). Environmental Sustainability: The adoption of green infrastructure not only offers financial benefits but also contributes to environmental sustainability. The integration of renewable energy systems, such as solar panels, significantly reduces carbon emissions and operational costs, contributing to more sustainable and resilient infrastructure. This inclusion serves as a reminder that financial optimization and environmental responsibility are not mutually exclusive, and that sustainable infrastructure development is achievable with the right planning and methodologies. e). Practical Implications for Stakeholders: The findings of this study offer valuable insights for a wide range of stakeholders involved in jetty retrofit projects, including engineers, project managers, policymakers, and investors. By demonstrating the effectiveness of VE and LCCA in optimizing both costs and long-term sustainability, the research provides practical guidance for decision-makers looking to integrate green infrastructure into future projects. This inclusion also emphasizes the importance of capacity building and regulatory support in ensuring the successful implementation of sustainable infrastructure solutions. f). Future Research Directions: The study suggests several avenues for future research, including the incorporation of risk analysis, cost uncertainty, and digital technologies such as Building Information Modeling (BIM). These areas of further investigation could enhance the efficiency of decision-making processes and expand the applicability of VE and LCCA in infrastructure development. Additionally, expanding the sample size and exploring the application of these methods in other infrastructure sectors could validate the findings and provide a broader understanding of cost optimization in sustainable development.

In summary, this study makes a significant contribution to the field of infrastructure cost optimization by applying Value Engineering and Life Cycle Cost Analysis to jetty retrofit projects. The findings offer valuable insights into the integration of green infrastructure in maritime facilities, providing both economic and environmental benefits. This research serves as a foundation for future work in sustainable infrastructure practices, offering practical guidance for stakeholders and contributing to the broader goal of achieving sustainable development in infrastructure projects.

DECLARATION OF AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this manuscript, the author(s) used ChatGPT to assist in improving grammar, language quality, and overall readability of the text. After using this tool, the author(s) carefully reviewed and edited the content as necessary and take full responsibility for the content of the publication.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.
Author 4: Formal analysis; Methodology; Writing - original draft.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Alavi, P., Jahanbakhsh Mashhadi, A., Rouhparvar, K., Joze Piri, A., Khalili, F., & Khatibi, A. (2025). A process model for industrial heritage adaptive reuse: Integrating environmental remediation and structural assessment. *International Journal of Building Pathology and Adaptation*, 1–19. https://doi.org/10.1108/IJBPA-09-2025-0244

Aouari, I., Rouabeh, A., Benahmed, B., & Lavorato, D. (2025). Damping reduction factors for vertical acceleration, velocity, and displacement response spectra in Italian seismic regions. *Structures*, *81*, 110178. https://doi.org/10.1016/j.istruc.2025.110178

Bi, Z., Mikkola, A., Ip, A. W. H., Yung, K. L., & Luo, C. (2025). Virtual Verification and Validation to Enhance Sustainability of Manufacturing Systems. *IEEE Transactions on Automation Science and Engineering*, *22*, 1738–1747. https://doi.org/10.1109/TASE.2024.3370053

Bocaneala, N., Mayouf, M., Vakaj, E., & Shelbourn, M. (2025). Artificial Intelligence Based Methods for Retrofit Projects: A Review of Applications and Impacts. *Archives of Computational Methods in Engineering*, *32*(2), 899–926. https://doi.org/10.1007/s11831-024-10159-7

Büyüksaraç, A., Avcil, F., Alkan, H., Işık, E., Harirchian, E., & Özçelik, A. (2025). Seismic Hazard Implications of the 2025 Balıkesir Earthquake of Mw 6.1 for Western Türkiye. *GeoHazards*, *6*(4), 64. https://doi.org/10.3390/geohazards6040064

Campagna, L. M., Carlucci, F., & Fiorito, F. (2025). School Energy Retrofit in a Changing Climate: Optimization of Retrofit Strategies and Cost Implications. In U. Berardi (Ed.), *Multiphysics and Multiscale Building Physics* (Vol. 553, pp. 238–244). Springer Nature Singapore. https://doi.org/10.1007/978-981-97-8309-0_31

Cao, P., Wang, J., Huang, D., Cao, Z., & Li, D. (2025). Evaluation and Analysis of Passive Energy Saving Renovation Measures for Rural Residential Buildings in Cold Regions:

A Case Study in Tongchuan, China. *Sustainability*, *17*(2), 540. https://doi.org/10.3390/su17020540

Cassol, D., Ingham, J., Dizhur, D., & Giongo, I. (2025). Analytical formulation describing the behaviour of URM walls seismically strengthened using timber strong-backs. *Engineering Structures*, *324*, 119343. https://doi.org/10.1016/j.engstruct.2024.119343

Chen, Z., Zhou, Y., Guo, Y., Zhong, G., Shi, F., & Fang, X. (2025). Empirical drift-based fragility function and loss estimation for the damped masonry infill wall in the reinforced concrete frame under in-plane cyclic loading. *Engineering Structures*, *343*, 120971. https://doi.org/10.1016/j.engstruct.2025.120971

Fan, J., Wang, P., Lu, Y., & Wu, Z. (2025). Seismic performance of RC frame structures retrofitted with external hybrid precast self-centering walls. *Structures*, *79*, 109466. https://doi.org/10.1016/j.istruc.2025.109466

Ferraioli, M., Pecorari, O., Mottola, S., & Diana, A. (2025). Dissipative steel exoskeletons for seismic retrofit of RC buildings. *Archives of Civil and Mechanical Engineering*, *25*(3), 134. https://doi.org/10.1007/s43452-025-01185-8

Gao, L., Zhou, Y., Cheng, F., Shi, S., Wang, Y., Zhang, R., & Wang, X. (2024). Application of arc elasticity analysis method combined with CO2 storage technology in building load and energy saving retrofit. *Thermal Science*, *28*(3 Part B), 2745–2764. https://doi.org/10.2298/TSCI2403745G

Gjoka, K., Rismanchi, B., & Crawford, R. H. (2025). Towards sustainable urban energy solutions: A multi-dimensional assessment framework for fifth-generation district heating and cooling systems. *Energy and Buildings*, *326*, 115071. https://doi.org/10.1016/j.enbuild.2024.115071

Goebel, K. (2024). Cybersecurity in Prognostics and Health Management. *International Journal of Prognostics and Health Management*, *15*(2). https://doi.org/10.36001/ijphm.2024.v15i2.4063

Guan, Q., & Zhou, Y. (2025). Utilizing ferrochrome slag and autoclaved artificial aggregates for eco-friendly and economical ultra-high-performance concrete: Mechanical performance and shrinkage control. *Case Studies in Construction Materials*, *22*, e04234. https://doi.org/10.1016/j.cscm.2025.e04234

He, W., Luo, J., Huang, J., Tang, C., & Yang, Z. (2024). Two-stage injection of polymer and microsand during ballasted flocculation for treating kaolin waters with or without humic acid: Floc evolutional characteristics, performance and mechanisms. *Water Research*, *259*, 121846. https://doi.org/10.1016/j.watres.2024.121846

Huang, W., Li, J., Zhou, Y., Chen, L., Xiang, J., Jiang, Z., Wang, X., Zhang, Q., & Xiang, Z. (2025). A Practical Methodology for Determining the Retrofit Prioritization of Aged GSU Transformers. *2025 International Conference of Clean Energy and Electrical Engineering (ICCEEE)*, 1–6. https://doi.org/10.1109/ICCEEE63357.2025.11156212

Ioannou, A. I., Pantazopoulou, S. J., Petrou, M. F., & Charmpis, D. C. (2025). Seismic retrofit of pre-damaged RC elements using thin strain-hardening cementitious composite jackets. *Bulletin of Earthquake Engineering*, *23*(5), 2171–2200. https://doi.org/10.1007/s10518-024-02090-w

Kavvada, I., Horvath, A., & Moura, S. (2024a). Distributionally Robust Budget Allocation for Earthquake Risk Mitigation in Buildings. *ASCE-ASME Journal of Risk and Uncertainty* *in Engineering Systems, Part A: Civil Engineering*, *10*(1), 04023050. https://doi.org/10.1061/AJRUA6.RUENG-1119

Kavvada, I., Horvath, A., & Moura, S. (2024b). Distributionally Robust Budget Allocation for Earthquake Risk Mitigation in Buildings. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*, *10*(1), 04023050. https://doi.org/10.1061/AJRUA6.RUENG-1119

Kumari, R. S., Kayalvizhi, N., & Anusha, V. (2025). An Deep Learning Framework for Thermal Analysis of The Green Wall System for Net Zero Building Approach. *2025 2nd International Conference on Artificial Intelligence and Knowledge Discovery in Concurrent Engineering (ICECONF)*, 1–9. https://doi.org/10.1109/ICECONF65644.2025.11379624

Laukotka, F. N., Berschik, M. C., & Krause, D. (2025). Towards improving the information management of aircraft cabin retrofits by processing quantity-on-hand documents. *Proceedings of the Design Society*, *5*, 3201–3210. https://doi.org/10.1017/pds.2025.10334

Liu, C., Chen, K., Li, F., Zhao, A., Liu, P., Chen, Z., Fang, Y., & Cao, Y. (2025). Unlocking Phase Purity of Sodium Iron Sulfate for Low-Cost and High-Performance Sodium-Ion Batteries. *Journal of the American Chemical Society*, *147*(17), 14635–14646. https://doi.org/10.1021/jacs.5c02485

Ma, H., Yang, Y., Xue, Z., Clarkson, C. R., & Chen, Z. (2025). Transitioning from emission source to sink: Economic and environmental trade-offs for CO2-enhanced coalbed methane recovery of Mannville coal Canada. *Science of The Total Environment*, *966*, 178721. https://doi.org/10.1016/j.scitotenv.2025.178721

Martin, P., Ocko, I. B., Esquivel-Elizondo, S., Kupers, R., Cebon, D., Baxter, T., & Hamburg, S. P. (2024). A review of challenges with using the natural gas system for hydrogen. *Energy Science & Engineering*, *12*(10), 3995–4009. https://doi.org/10.1002/ese3.1861

Muratoglu, T., & Erturk, A. T. (2025). Enhanced Strain Measurement Accuracy in Metallic Tensile Testing Through Video Extensometry: A Comparative Analysis. In J. Ma, R. Masrour, A. Gloria, K. Wang, & Sanjay M R (Eds.), *Advances in Transdisciplinary Engineering*. IOS Press. https://doi.org/10.3233/ATDE250991

Pais, F., Sousa, N., Coutinho-Rodrigues, J., & Natividade-Jesus, E. (2026). Walking and cycling friendliness as proxies to retrofit active transport infrastructure. *Proceedings of the Institution of Civil Engineers - Municipal Engineer*, *179*(1), 31–44. https://doi.org/10.1680/jmuen.24.00021

Panadés, K., Olbina, S., & Kohlman Rabbani, E. R. (2026). Social sustainability in building retrofit projects: A systematic literature review. *International Journal of Building Pathology and Adaptation*, *44*(4), 1098–1120. https://doi.org/10.1108/IJBPA-02-2025-0032

Puchtler, S., & Kirchner, E. (2025). Capacitance Calculation of Ball Bearings An Open-Source Model. *Tribology Transactions*, *68*(4), 912–924. https://doi.org/10.1080/10402004.2025.2525813

Taylor, A., O'Neill, J., & Naughton, C. (2025). RETROFITTING LOW-RISE BUILDING STOCK THROUGH MASS TIMBER ADDITIONS AND PERFORMANCE-BASED FIRE ENGINEERING: DARLINGHURST WORKPLACE. *World Conference on Timber Engineering 2025*, 901–910. https://doi.org/10.52202/080513-0112

Toledo, A. L. L., Da Silva, E. S., Clemente, J. C., Dos Santos, M. C., Oliveira, M. C. R., De Medeiros, I. B. B. G., & Freire, J. T. C. (2025). Retrofitting Buildings as an Instrument of Historical Preservation: Case Study of the Escola de Aprendizes Artífices, Natal, Brazil. In F. M. Mazzolani, R. Landolfo, & B. Faggiano (Eds.), *Protection of Historical Constructions* (Vol. 596, pp. 529–536). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-87316-4_64

Ulyev, L. M., & Chernyshov, M. N. (2025a). Energy efficiency potential determination for an oil treatment and stabilization unit at the field. *Bulletin of the Tomsk Polytechnic University Geo Assets Engineering*, *336*(1), 169–182. https://doi.org/10.18799/24131830/2025/1/4864

Ulyev, L. M., & Chernyshov, M. N. (2025b). Energy efficiency potential determination for an oil treatment and stabilization unit at the field. *Bulletin of the Tomsk Polytechnic University Geo Assets Engineering*, *336*(1), 169–182. https://doi.org/10.18799/24131830/2025/1/4864

Vesho, N., Guri, M., & Sava, A. (2024). The use of numerical models within the BIM environment, for the issue of Cultural heritage restoration. Buildings designed until 1940 in Albania. *Architecture, Structures and Construction*, *4*(1), 37–53. https://doi.org/10.1007/s44150-023-00106-8

Wang, J., Guo, T., Xie, Y., & Zhang, Y. (2025). Self-centering tension brace for seismic damage mitigation: From real-time hybrid simulation test to performance-based seismic retrofit design. *Engineering Structures*, *332*, 120135. https://doi.org/10.1016/j.engstruct.2025.120135

Widodo, W., Suhardjono, S., & Effendi, M. K. (2025). DESIGN AND ANALYSIS STRUCTURAL AT RETROFIT UNIVERSAL TURN DRILL MACHINE. *Proceedings on Engineering Sciences*, *7*(2), 829–840. https://doi.org/10.24874/PES07.02.011