Cost-Benefit Sharing framework through Sustainable Value Engineering: A Continuous Stage-Wise Waste Reduction Approach

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Abstract
This study introduces a novel cost-benefit sharing framework for sustainable construction value engineering (VE), highlighting a phased waste reduction approach that incorporates artificial intelligence (AI). The framework promotes collaboration among essential stakeholders, including contractors, consultants/designers, and clients, ensuring that each project phase adheres to environmental sustainability objectives while realizing substantial cost and resource reductions. A thorough examination of traditional VE methods and their shortcomings is performed, emphasizing the capacity of AI to revolutionize VE practices for a more sustainable and economically feasible future. A framework utilizing artificial intelligence is developed to improve material selection and forecast waste generation, hence improving decision-making processes. The framework's effectiveness is evidenced by its capacity to minimize waste, enhance resource allocation, and fairly distribute financial benefits among stakeholders, thus promoting its use in the construction industry.

Keywords
Construction management, cost-benefit, sustainability, waste valorization, value engineering.

1. Introduction
Value engineering (VE) in construction is defined as a systematic and organized approach to maximize project value by carefully examining project functions and components. Its primary goal is to enhance performance (Tom and Gowrisankar, 2015), efficiency, quality, and sustainability while minimizing costs (Al Amri and Marey-Pérez, 2020), leading to an enhanced function-to-cost ratio. VE improves industry standards and significantly increases business profits (Cheah and Ting, 2005) by encouraging creative thinking and long-term competitiveness.
Quality, cost, and time are three essential elements of construction management. While the use of suitable construction techniques is vital for cost effectiveness, frequent design modifications and low-bid contractor selection often result in substantial financial challenges (Khaleel, 2021). VE assesses different alternatives, materials, and construction techniques (Robati et al., 2021) to identify potential for cost reduction and maximize the value of an investment as illustrated in Figure 1. Additionally, VE promotes sustainability by incorporating recyclable materials and initiatives to minimize carbon footprint. It detects design deficiencies and accelerates project timelines, enhancing overall quality (Atabay and Galipogullari, 2013).

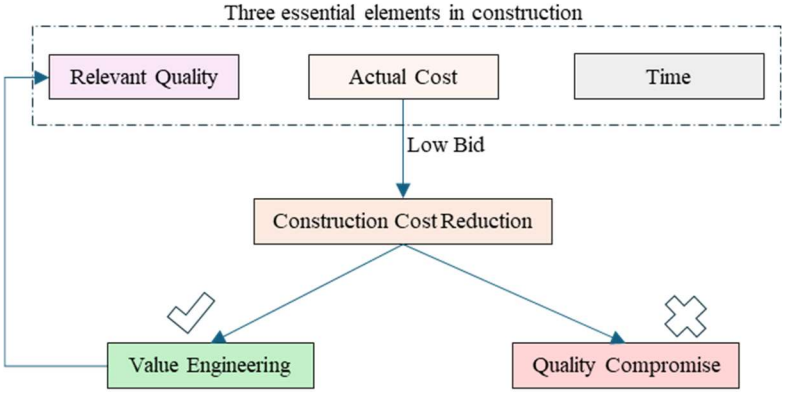

Figure 1 Essential Elements of Construction (author's work)

The model depicted in Figure 2 demonstrates a methodical approach to material selection within the VE framework. The process involves data collection, functional analysis, creativity and alternative solutions, evaluation of environmental impacts, and final establishment of materials. AI tools are incorporated to manage large datasets, predict environmental outcomes, and facilitate decision-making processes (Yu et al., 2020, Janani et al., 2018). As the

process progresses, the importance of creativity and alternatives becomes inevitable. This necessitates the creation of novel concepts and the examination of different potentialities prior to providing well-informed suggestions (Chaphalkar and Patil, 2011, Zhang et al., 2009). This step involves the adaptation of the decision-making framework to incorporate new materials that may be unconventional yet efficient. Also, during the creative phase, an assessment is performed to appraise the alternatives according to their life expectancy, quality, and other inherent characteristics. This analytical step also takes into account the environmental consequences, including the release of greenhouse gases, and requires a life cycle study to precisely quantify these emissions(Latief et al., 2017). Ultimately, the process reaches its final stage in the establishment which centers on assessing the economic and technological feasibility of the materials. Here, the input of experts are taken to verify that the chosen materials' functional and aesthetic criteria in accordance with sustainable value engineering concepts(Mesbah, 2014). The process underscores the significance of not only cutting costs and improving aesthetics, but also taking into account time considerations, with the goal of eliminating unnecessary effort and expenses(Liang et al., 2023). This approach promotes harmonious satisfaction among owners, designers, and contractors by strategically choosing durable, cost-effective, and visually pleasing materials.

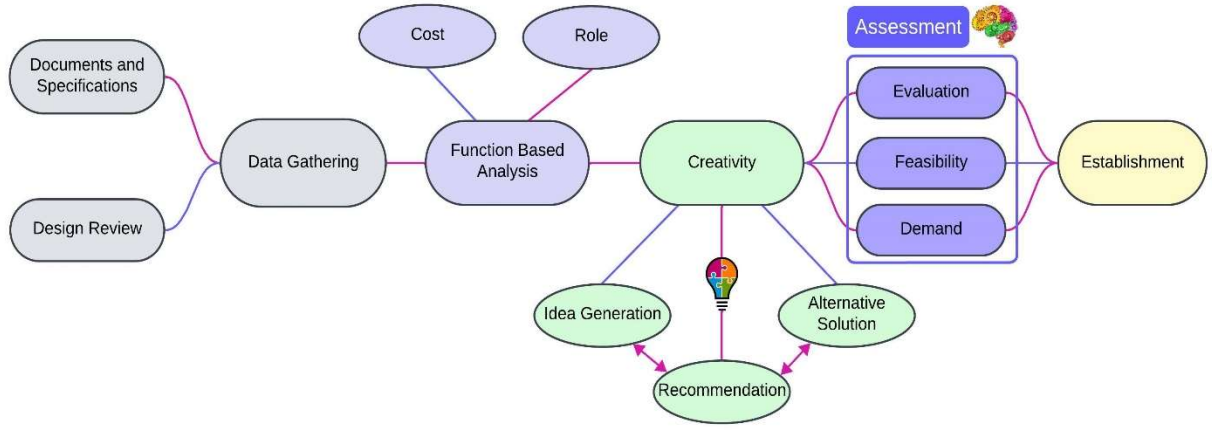

Figure 2 Material Choice Technique in Value Engineering (author's work)

Despite recognized benefits, VE implementation faces challenges such as lack of skilled personnel, resistance to change, inadequate documentation, and high costs of technological integration (Othman et al., 2021). This study aims to address these challenges through an AI-integrated framework that emphasizes sustainability and stakeholder value sharing.

2. Methodology

The study employs a multi-phase methodology (Figure 3) to develop a cost-benefit sharing framework for sustainable VE. A comprehensive literature study outlines current VE practices and potential integration opportunities for AI. The suggested framework integrates the 3R principles (Reduce, Reuse, Recycle) and utilizes AI models, such as neural networks and support vector machines, to enhance material efficiency and forecast the generation of waste. Mechanisms for sharing dividends among stakeholders are implemented to promote adoption of VE.

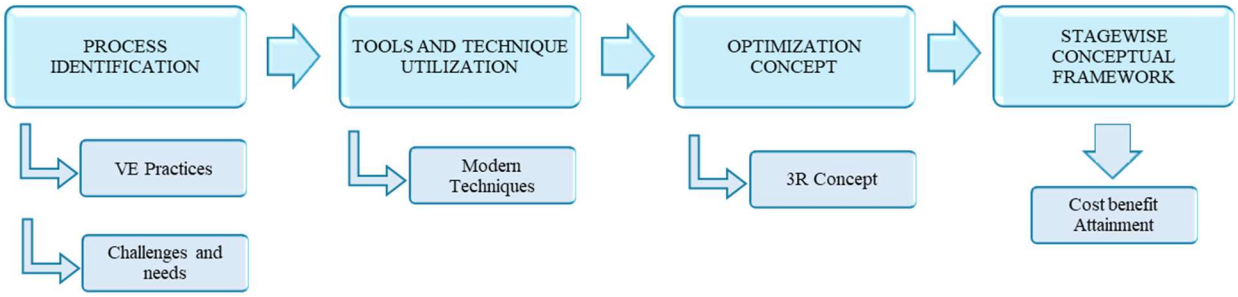

Figure 3 Methodology flow chart (author's work)

2.1 Challenges in VE implementation

VE is acknowledged as an essential approach for improving project results via cost reduction and efficiency enhancements. However, its execution in the building industry encounters several organizational and technological obstacles. Principal problems comprise a deficiency of competent experts and widespread opposition to change, frequently stemming from negative beliefs and insufficient information (Kim et al., 2016). The challenges are intensified by inadequate documentation, insufficient specifications, and a deficiency in organizational support mechanisms, obstructing wider adoption. Table 1 represents some of the major VE problems and their associated effects as identified in previous research.

The incorporation of modern technologies into VE presents intriguing solutions while also introducing new difficulties. Substantial initial investments, ongoing expenses, and the technical challenges of integrating new technologies into established workflows pose considerable obstacles (Othman et al., 2021). Moreover, VE projects that concentrate solely on cost reduction compromise quality and precision, resulting in inferior outcomes. Concerns regarding transparency, accountability, and administrative issues further impede adoption (Kissi et al., 2017). Opposition from stakeholders such as clients and designers imposing stringent material standards or contractors emphasizing profit margins, compounds the difficulty. Insufficient data, obsolete standards, and disjointed communication hinder efficient VE procedures (Atabay and Galipogullari, 2013).

Surmounting these obstacles necessitates a comprehensive strategy that integrates technological advancement with organizational cooperation. Yan (Yan, 2012) underscores the importance of access to a varied skill set and interdepartmental collaboration. Advanced technologies, especially AI-driven collaborative platforms, can facilitate the closure of knowledge gaps and optimize VE processes. They facilitate real-time data exchange, predictive analysis, and stakeholder participation, thereby diminishing opposition and cultivating a culture of innovation.

Table 1 Challenges and Outcomes of Value Engineering

Sl No.	Reference	Challenges	Outcomes
1	(Rwelamila and Savile, 1994)	• Requirement for a suitable instrument that enables the project group to generate value, reconcile conflicting needs and limits on a project.	• Using hybrid value engineering (HVE) as a management tool, choices may be made with more understanding and project performance can be increased.
2	(Bresnen and Marshall, 2000)	• VE limited to front-end level	• Early contractor involvement especially at design stage to improve buildability
3	(SHFN, 2001)	• Insufficient structured processes and tools, • Ineffective communication and coordination, • Challenges in finding and assessing alternatives	• Use of modern technology tools including video conferencing, document sharing online, and virtual brainstorming • Systematic strategy for growth and enhancement with potential for experimentation and risk-taking
4	(Chan et al., 2004)	• Uncertainty, a lack of communication, and problems with trustworthiness • Contradiction between expectations and objectives • Reluctance to pool resources and bring out novel ideas	• Encouraging an attitude that prioritizes resource sharing and idea exchange • Collaboration Possibilities for sharing resources with incentives and rewards
5	(Aarseth et al., 2012)	• Absence of Initiative • Uncertain duties and obligations • A lack of comprehension of partnering ideas	• Establishment of a workable model with guidelines and management structure. • Key results condensed to aid in the creation of ideas and concepts for the partnership model
6	(Ramli et al., 2013)	• Time and attitude related issues, • Knowledge, information gaps and lack of	• Increased stakeholder engagement and communication

		internal resources, • Resistance to change.	• Staff education and training
7	(De Melo et al., 2016)	• Costly conventional methods • Contractor's lack of shared incentives	• Using financial, time, and productivity incentives to promote stronger teamwork • Appropriate strategies for implementation and assessment
8	(Oke and Aigbavboa, 2017)	• Time elapsed and approached • Cost of Operation • Barriers to involvement and commitment from clients • Project Specifications and the Purchasing Solutions	• Social Consciousness • Using contemporary tools like electronic value management, virtual teamwork, and Delphi procedures • Providing financial incentives
9	(Kineber et al., 2020)	• Awareness • Processing in construction projects	• Disclosure of details for implementation • Knowledge enhancement of carrying out the process
10	(Giménez et al., 2022)	• A lack of integration of the builder and early cost-cutting strategies • Insufficient use of new technologies for digital communication	• Target Value Design strategy to reach previously determined project cost from the design stage • Work based on precise estimates, buildability and issue-based decision-making

2.2 Modern techniques in Value Engineering

Modern VE utilizes digital technologies to surmount conventional constraints and unveil novel avenues for value creation (Aghimien et al.). Building Information Modeling (BIM) has become a crucial facilitator, enhancing visualization, precise cost estimation, and real-time monitoring across the project lifecycle (Aghimien et al.; Park et al., 2017). BIM functions as an inventory for VE concepts and a collaborative platform for informed material and design decisions (Park et al., 2017). The incorporation of AI significantly augments VE capabilities. AI models, including neural networks, support vector machines, and fuzzy logic systems, facilitate predictive analytics for cost estimation and project optimization under unpredictable conditions (Elmousalami, 2020, Elfaki et al., 2014, Kim et al., 2013). These technologies may evaluate intricate datasets to predict expenditures, pinpoint cost-saving options, and enhance material allocation and resource use. Hybrid methodologies that integrate AI with case-based reasoning enhance prediction precision and variation control by leveraging prior project data (Chen and Hsu, 2007, Abiodun et al., 2018).These improvements establish AI-enabled VE frameworks as revolutionary mechanisms for achieving sustainable, efficient, and economical construction outcomes.

2.3 Material usage by 3R concept

The 3R (Reduce, Reuse, Recycle) principles are promising pathway towards sustainable VE practices. Reduction techniques focus on design modifications, dimensional uniformity, and prefabrication to decrease material waste (Akhund et al., 2019, Akinade, 2017). Reuse programs advocate for the repurposing of materials such as concrete, bricks, glass, and wood, hence mitigating environmental impacts and preserving resources (Silva et al., 2019). Innovative sustainable materials including bamboo, indigenous stone, and engineered wood products offer further prospects for reducing environmental impacts (Madhushan et al., 2023, Asiz, 2023, Meddah et al., 2019). These improvements not only conform to ecological objectives but also provide market uniqueness and financial benefits through distinctive architectural solutions (Begum et al., 2006). The use of AI technology into VE can enhance these 3R activities by facilitating data-driven decision-making regarding material selection, life-cycle assessments, and environmental impact evaluations.

This amalgamation of problems, technical advancements, and sustainable methodologies highlights the necessity for a comprehensive, AI-integrated VE framework. A framework must proficiently tackle implementation obstacles, utilize contemporary tools like as BIM and AI, and incorporate sustainability principles to attain cost-benefit optimization and stakeholder alignment.

3. Conceptual Framework Development

Figure 4 illustrates a novel conceptual framework for the integration of VE with AI to enhance sustainability, improve resource allocation, and facilitate equitable cost-benefit distribution in building projects. Though the framework encompasses all phases of the construction lifecycle such design and planning, procurement, construction, operation and maintenance, and demolition; primary focus is in the construction stage where material-related decisions have a great impact. The framework bolstered by AI driven methodologies include ML models that forecast material quantities, assess environmental implications, and enhance allocation techniques. These solutions enable material substitute and optimization processes that reduce waste, conserve resources, and improve cost efficiency.

The methodology further demonstrates how these savings result in sustainability improvements, resource conservation, and measurable cost reductions. A cost-benefit sharing system is used to distribute financial benefits equally among stakeholders such as contractors, consultants/designers and clients through a profit-sharing model. (Liu et al., 2023). This promotes the concept of incentive sharing for enabling value engineering. Additionally, this mitigates prevalent obstacles such as resistance to change and financial limitations (Gounder et al., 2023, Miraj et al., 2021). Advanced AI techniques such as Recurrent Neural Networks (RNN), enhance the precision of financial forecasting and policy alignment, hence reinforcing long-term sustainability through VE practices.

This framework offers a strategic approach to transform conventional VE methods into comprehensive, data-driven, and economically sustainable solutions for the building section by integrating technical innovation with sustainable development principles and stakeholder participation.

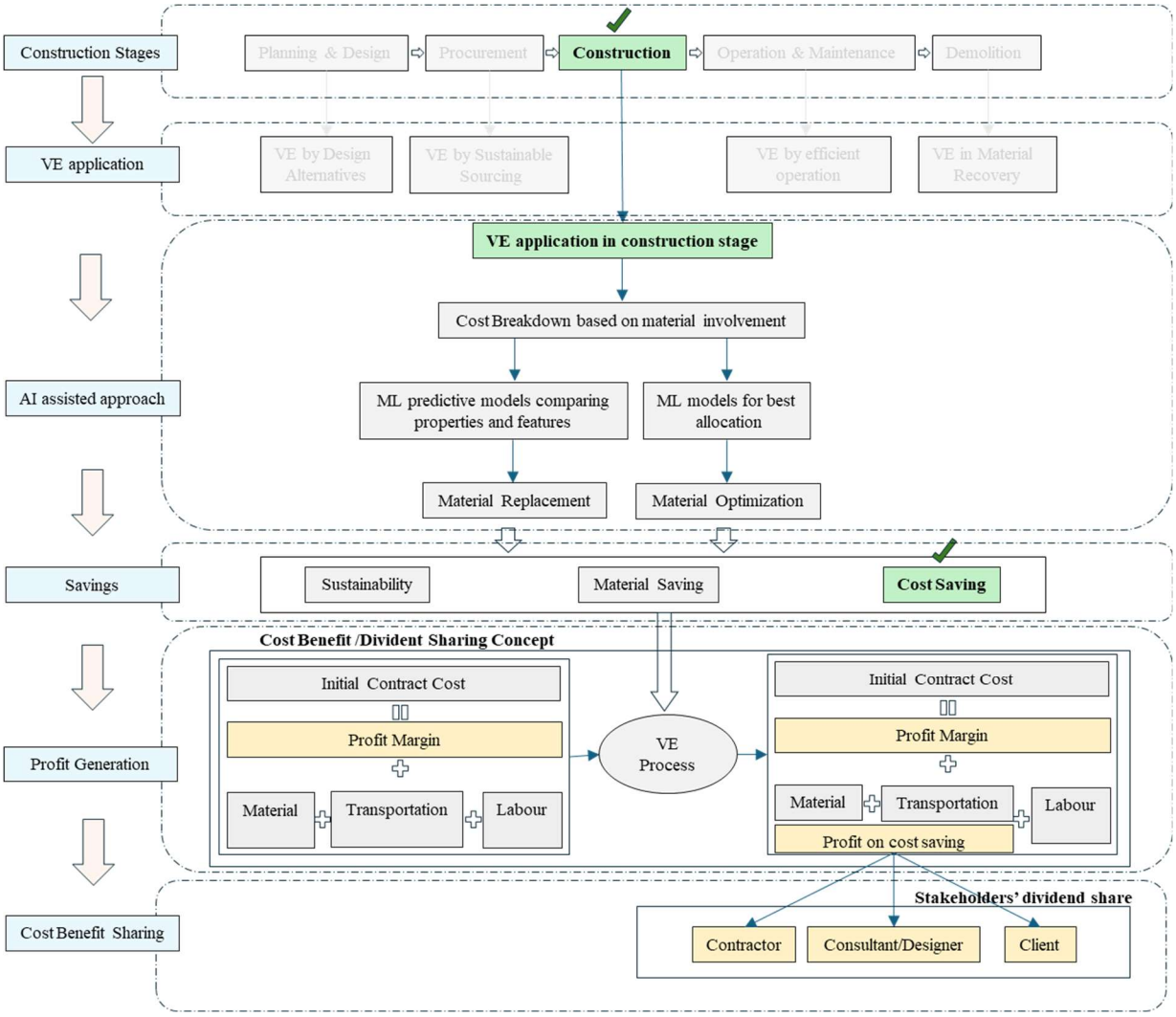

Figure 4 Conceptual Framework Model for Value Engineering and Cost-Benefit Sharing (Author's work)

4. Discussion

A rational design approach requires meticulous evaluation of cost reduction options and benefit evaluations to guarantee energy efficiency and total project value. VE is essential for optimizing cost, function, and quality, allowing construction projects to meet their goals without excessive expenditures. Inadequate planning frequently results in retrofitting or demolition, hence elevating energy demand, resource utilization, and related expenses (Wei and Chen, 2020). To address these difficulties, various studies highlight the implementation of ecologically sustainable procedures and materials that diminish the environmental impact of construction activities. Recent improvements in VE have underscored an increasing interest in incorporating AI to improve decision-making and optimize material selection. The capacity of AI to analyze intricate datasets, simulate design scenarios, and assess environmental implications establishes it as a crucial tool for sustainable development. Utilizing ML, data analytics, and automation, AI-driven VE frameworks can substantially enhance project outcomes, aligning building techniques with sustainability goals and promoting the effective use of resources.

The use of AI in VE not only advances environmental and economic objectives but also develops novel strategies for minimizing waste and enhancing project performance. The collaboration between AI and sustainability signifies a transformative movement towards data-driven, environmentally responsible, and economically feasible construction methods. The effective execution of AI-enhanced VE frameworks depends significantly on strong policy formulation and proactive stakeholder involvement. Saradara (Saradara et al., 2023), asserts that meticulously crafted regulatory frameworks are crucial for navigating technological difficulties an guaranteeing uniform, effective practices.

Collaborative policymaking among clients, contractors, and designers can facilitate the smooth integration of AI tools and advance sustainable construction practices. This highlights the essential requirement for collaborative initiatives within the industry to transform technology innovations into viable and scalable solutions.

5. Limitations

The study primarily examines the cost dimension of value engineering and presents a conceptual framework that has not yet been empirically validated. Subsequent research should include surveys, expert interviews, and case studies to evaluate its practical relevance and enhance the framework informed by real-world observations. Moreover, involving industry experts in the assessment process may improve its pertinence and flexibility. The creation of intuitive digital tools or applications based on the framework could enhance its acceptance among construction stakeholders. This research focuses on cost-sharing methods in VE, but future studies could broaden the scope to encompass other essential elements like quality, functionality, and environmental sustainability.

6. Conclusions

This paper presents an AI-integrated VE framework aimed at improving sustainable construction practices through improved material selection, waste minimization, and cost-benefit distribution. The system promotes collaborative decision-making and equitable distribution of project savings by utilizing ML models and implementing a stakeholder-oriented dividend-sharing mechanism. The use of the 3R principles enhances environmental sustainability, optimizes resource utilization, and increases overall project efficiency. This framework's practical significance resides in its ability to connect traditional VE methodologies with the evolving requirements of modern construction projects. It provides a systematic framework for contractors, consultants, and customers to jointly attain economic, environmental, and functional goals. Moreover, its versatility across several project dimensions and contexts renders it an essential instrument for promoting sustainability objectives across the sector.

References

Aarseth, W., Andersen, B., Ahola, T. & Jergeas, G. 2012. Practical difficulties encountered in attempting to implement a partnering approach. *International journal of managing projects in business,* 5**,** 266-284.

Abiodun, O. I., Jantan, A., Omolara, A. E., Dada, K. V., Mohamed, N. A. & Arshad, H. 2018. State-of-the-art in artificial neural network applications: A survey. *Heliyon,* 4.

Aghimien, D., Ngcobo, N. & Clinton, A. Digital technologies for Effective Value Management in the Construction Industry.

Akhund, M., Memon, A., Ali, T., Memon, N. & Kazi, S. 2019. Waste management in construction projects of pakistan. *Pakistan Journal of Science,* 71**,** 59.

Akinade, O. O. 2017. *BIM-based software for construction waste analytics using artificial intelligence hybrid models.* University of the West of England Bristol.

Al Amri, T. & Marey-Pérez, M. 2020. Value engineering as a tool for sustainability in the construction industry of Oman. *Value Eng,* 29**,** 7433-7444.

Asiz, A. 2023. Sustainable Timber Construction: Challenges and Opportunities. *International Journal of Engineering and Science Applications,* 10**,** 13-21.

Atabay, S. & Galipogullari, N. 2013. Application of value engineering in construction projects. Dec.

Begum, R. A., Siwar, C., Pereira, J. J. & Jaafar, A. H. 2006. A benefit–cost analysis on the economic feasibility of construction waste minimisation: The case of Malaysia. *Resources, conservation and recycling,* 48**,** 86-98.

Bresnen, M. & Marshall, N. 2000. Building partnerships: case studies of clientcontractor collaboration in the UK construction industry. *Construction management and economics,* 18**,** 819-832.

Chan, A. P., Chan, D. W., Chiang, Y. H., Tang, B.-S., Chan, E. H. & Ho, K. S. 2004. Exploring critical success factors for partnering in construction projects. *Journal of construction engineering and management,* 130**,** 188-198.

Chaphalkar, N. B. & Patil, N. A. 2011. Study of Value Engineering Creativity Phase for Highway Project by Using TRIZ Techniques. *International Journal on Emerging Technologies,* 2**,** 114-121.

Cheah, C. Y. & Ting, S. K. 2005. Appraisal of value engineering in construction in Southeast Asia. *International journal of project management,* 23**,** 151-158.

Chen, J.-H. & Hsu, S.-C. 2007. Hybrid ANN-CBR model for disputed change orders in construction projects. *Automation in Construction,* 17**,** 56-64.

De Melo, R. S. S., Do, D., Tillmann, P., Ballard, G. & Granja, A. D. 2016. Target value design in the public sector: evidence from a hospital project in San Francisco, CA. *Architectural Engineering and Design Management,* 12**,** 125-137.

Elfaki, A. O., Alatawi, S. & Abushandi, E. 2014. Using intelligent techniques in construction project cost estimation: 10-year survey. *Advances in Civil engineering,* 2014.

Elmousalami, H. H. 2020. Comparison of artificial intelligence techniques for project conceptual cost prediction: a case study and comparative analysis. *IEEE Transactions on Engineering Management,* 68**,** 183-196.
Giménez, Z., Mourgues, C., Alarcón, L. F. & Mesa, H. 2022. Exploring value generation in target value design applying a value analysis model. *Buildings,* 12**,** 922.
Gounder, S., Hasan, A., Shrestha, A. & Elmualim, A. 2023. Barriers to the use of sustainable materials in Australian building projects. *Engineering, Construction and Architectural Management,* 30**,** 189-209.
Janani, R., Chakravarthy, P. & Raj, D. R. R. 2018. A study on value engineering & green building in residential construction. *International Journal of Civil Engineering and Technology,* 9**,** 900-907.
Khaleel, O. 2021. Assessment of the Smart Construction Plan for Oman Vision 2040. *Journal of Student Research*.
Kim, G.-H., Shin, J.-M., Kim, S. & Shin, Y. 2013. Comparison of school building construction costs estimation methods using regression analysis, neural network, and support vector machine.
Kim, S.-Y., Lee, Y.-S. & Nguyen, V. T. 2016. Barriers to applying value management in the Vietnamese construction industry. *Journal of Construction in Developing Countries,* 21**,** 55.
Kineber, A. F., Othman, I., Oke, A. E., Chileshe, N. & Buniya, M. K. 2020. Identifying and assessing sustainable value management implementation activities in developing countries: The case of Egypt. *Sustainability,* 12**,** 9143.
Kissi, E., Boateng, E. B., Adjei-Kumi, T. & Badu, E. 2017. Principal component analysis of challenges facing the implementation of value engineering in public projects in developing countries. *International Journal of Construction Management,* 17**,** 142-150.
Latief, Y., Berawi, M. A., Basten, V. & Budiman, R. Construction performance optimization toward green building premium cost based on Greenship rating tools assessment with value engineering method. Journal of Physics: Conference Series, 2017. IOP Publishing, 012041.
Liang, Q., Liang, H., Li, Q., Tam, V. W., Yu, J. & Zhu, L. 2023. Function matters: Development of a value engineering building–function–assessment framework from stakeholders' perspectives using hybrid analytical methods. *Journal of Building Engineering,* 68**,** 106025.
Liu, Y., Hao, J., Li, C., Li, Y., Zhou, C., Zheng, H., Xu, S., Chen, W. & Li, X. 2023. How Can Construction and Demolition Waste Recycling Public–Private Partnership Projects Performance Compensate during the Operation Period? A Two-Stage Perspective of Recycling and Remanufacturing. *Systems,* 11**,** 170.
Madhushan, S., Buddika, S., Bandara, S., Navaratnam, S. & Abeysuriya, N. 2023. Uses of Bamboo for Sustainable Construction—A Structural and Durability Perspective—A Review. *Sustainability,* 15**,** 11137.
Meddah, M. S., Benkari, N. & Al-Busaidi, M. Potential Use of Locally and Traditionally Produced Bending Construction Material. IOP Conference Series: Materials Science and Engineering, 2019. IOP Publishing, 042008.
Mesbah, M. 2014. *Value management for construction projects via an expert system framework.* Eastern Mediterranean University (EMU)-Doğu Akdeniz Üniversitesi (DAÜ).
Miraj, P., Berawi, M. A. & Utami, S. R. 2021. Economic feasibility of green office building: combining life cycle cost analysis and cost–benefit evaluation. *Building Research & Information,* 49**,** 624-638.
Oke, A. E. & Aigbavboa, C. O. 2017. *Sustainable value management for construction projects*, Springer.
Othman, I., Kineber, A., Oke, A., Zayed, T. & Buniya, M. 2021. Barriers of value management implementation for building projects in Egyptian construction industry. *Ain Shams Engineering Journal,* 12**,** 21-30.
Park, C.-S., Kim, H.-J., Park, H.-T., Goh, J.-H. & Pedro, A. 2017. BIM-based idea bank for managing value engineering ideas. *International Journal of Project Management,* 35**,** 699-713.
Ramli, A., Sulaiman, S. & Mitchell, F. 2013. Challenges in management accounting innovation adoption: Evidence from Malaysian companies. *International Journal of Finance and Accounting,* 2**,** 125-130.
Robati, M., Oldfield, P., Nezhad, A. A., Carmichael, D. G. & Kuru, A. 2021. Carbon value engineering: A framework for integrating embodied carbon and cost reduction strategies in building design. *Building and environment,* 192**,** 107620.
Rwelamila, P. & Savile, P. 1994. Hybrid value engineering: the challenge of construction project management in the 1990s. *International journal of project management,* 12**,** 157-164.
Saradara, S. M., Khalfan, M. M. A., Rauf, A. & Qureshi, R. 2023. On the path towards sustainable construction—the case of the United Arab Emirates: a review. *Sustainability,* 15**,** 14652.
SHFN, Q. 2001. Using Information Technology to Overcome Difficulties in Value Manage1nent Studies-Hong Kong's Experience.
Silva, R., De Brito, J. & Dhir, R. 2019. Use of recycled aggregates arising from construction and demolition waste in new construction applications. *Journal of Cleaner Production,* 236**,** 117629.

Tom, N. & Gowrisankar, V. 2015. Value engineering in residential house construction. *International Journal of Civil Engineering,* 6.

Wei, T. & Chen, Y. 2020. Green building design based on BIM and value engineering. *Journal of Ambient Intelligence and Humanized Computing,* 11**,** 3699-3706.

Yan, L. Value engineering application in construction project management. 2012 International Conference on Industrial Control and Electronics Engineering, 2012. IEEE, 1265-1268.

Yu, M., Robati, M., Oldfield, P., Wiedmann, T., Crawford, R., Nezhad, A. A. & Carmichael, D. 2020. The impact of value engineering on embodied greenhouse gas emissions in the built environment: A hybrid life cycle assessment. *Building and Environment,* 168**,** 106452.

Zhang, X., Mao, X. & AbouRizk, S. M. 2009. Developing a knowledge management system for improved value engineering practices in the construction industry. *Automation in construction,* 18**,** 777-789.