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Analysis of the Use of Environmentally Friendly Building Materials and Construction Waste Management on Cost Efficiency and Project Sustainability in Karawang

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ABSTRACT

This study investigates the impact of environmentally friendly building materials and construction waste management on cost efficiency and project sustainability in Karawang. A quantitative analysis was conducted using a sample of 150 respondents from the construction sector, with data collected through a structured survey based on a Likert scale of 1 to 5. Structural Equation Modeling-Partial Least Squares (SEM-PLS 3) was employed to analyze the relationships between the variables. The results show that both environmentally friendly materials and construction waste management significantly improve cost efficiency and project sustainability. Construction waste management exhibited a stronger influence on both outcomes, emphasizing its importance in reducing costs and promoting environmental responsibility. The findings suggest that adopting sustainable construction practices can enhance financial performance while contributing to long-term sustainability, offering valuable insights for construction companies and policymakers.

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1. INTRODUCTION

The construction industry plays a significant role in economic development and environmental sustainability, with sustainable practices such as material use and waste management essential for reducing its environmental impact. In the UAE, there is a shift towards using locally sourced, recyclable, and renewable materials to enhance both environmental and project performance [1]. Sustainable alternatives like polymer concrete and bamboo fibre geopolymer are being explored to replace carbon-intensive materials like concrete [2]. Green buildings, designed for energy efficiency, help lower environmental footprints and contribute to sustainability [3], especially as construction consumes about 40% of global energy [4]. Developed nations have implemented environmental management systems like ISO 14001, but face challenges with standardisation and enforcement [5]. While progress is being made, issues such as behavioural adoption and material standardisation persist, requiring coordinated efforts and stronger policies for successful implementation [5].

Balancing economic viability with environmental responsibility in construction is challenging, as traditional methods often prioritize cost and speed, leading to waste and reliance on non-renewable materials. The use of sustainable materials in the UAE, such as locally sourced and recyclable options, reduces environmental impact and enhances energy efficiency and indoor air quality [1]. Though green materials may have higher initial costs, they provide long-term benefits, as seen in projects like the TECLA 3D printed house [6]. The circular economy approach, which promotes waste reduction and recycling, generates both environmental and economic advantages [7]. However, high costs, inadequate funding, and weak waste management systems, especially in Nigeria, hinder sustainable practice adoption [8]. Green buildings offer a solution by reducing CO2 emissions from cement and steel production [3].

The rapid growth of Karawang's construction sector presents an opportunity to implement sustainable practices. Using eco-friendly materials like polymer concrete and bamboo fibre geopolymer can reduce carbon emissions and resource wastage [9]. Advanced materials such as Cross-Laminated Timber (CLT) and coated glass enhance building durability and energy efficiency, as seen in projects like The Edge in Amsterdam [10]. Effective waste management, demonstrated by the Eden project, and partnerships like the Karawang Health Centre's collaboration with third-party waste managers, are crucial, though improvements in storage and environmental accounting are needed (5). Sustainable practices, evidenced by West Java's automotive industry, can lower carbon emissions and improve cost efficiency [11]. However, addressing challenges in human resources and environmental accounting is essential for Karawang to fully benefit from sustainable construction [12]. The importance of this study lies in its potential to offer actionable recommendations for construction companies, policymakers, and stakeholders in Karawang and beyond [13].

2. LITERATURE REVIEW

2.1 *Environmentally Friendly Building Materials*

Environmentally friendly building materials, also known as sustainable or green materials, are those with minimal environmental impact throughout their lifecycle, from production to disposal. These materials are responsibly sourced, often renewable, and contribute to reduced energy consumption during construction [6]. Studies have shown that using sustainable building materials can significantly lower carbon emissions, improve energy efficiency, and enhance the overall sustainability of construction projects [14], [15]. Popular eco-friendly materials include recycled steel, bamboo, and low-VOC paints. According to [16]–[18], the use of these materials also results in long-term cost savings due to reduced energy consumption and lower maintenance costs. While the initial cost of some sustainable materials may be higher, their ability to improve energy efficiency and reduce repair needs over time often leads to a lower total cost of ownership, underscoring the importance of considering lifecycle costs rather than just initial expenses in evaluating the economic viability of green materials in construction.

2.2 *Construction Waste Management*

Construction waste management involves strategies to reduce, recycle, and properly dispose of waste generated during construction activities, which typically produce significant amounts of waste like concrete, wood, metal, and packaging materials. Poor waste management can lead to environmental pollution, increased costs, and project inefficiencies [19]. Effective waste management not only reduces landfill waste but also contributes to cost savings through recycling and material reuse [7], [20]. Research highlights that construction waste management is crucial for project sustainability, as [21], [22] argue that it aligns with the circular economy concept, aiming to minimize resource consumption by keeping materials in use longer. By adopting recycling and reuse strategies, construction companies can lower material costs, reduce waste disposal expenses, and improve their projects' environmental performance.

2.3 *Cost Efficiency in Construction*

Cost efficiency in construction refers to minimizing expenses while achieving desired outcomes by optimizing materials, labor, and resources without compromising quality. Studies have shown a strong relationship between sustainable practices and cost efficiency [23]. For instance, [24] found that projects using green building materials and effective waste management strategies tend to have lower operational costs over time due to energy savings, reduced waste disposal costs, and increased resource efficiency. Although the initial costs of sustainable practices may be higher, the long-term benefits often outweigh these expenses. By improving efficiency and reducing the need for expensive waste disposal services, sustainable materials contribute to overall cost reduction. Additionally, government incentives and certifications for green construction can further enhance the cost-effectiveness of sustainable practices [25], [26].

2.4 *Project Sustainability*

Project sustainability in the construction sector refers to ensuring long-term viability by addressing environmental, social, and economic factors. Sustainable projects minimize environmental impacts, contribute to community well-being, and ensure economic profitability [27]. Integrating sustainability into the design, planning, and execution phases is crucial, with the use of environmentally friendly materials and effective waste management playing key roles [28], [29]. These practices reduce a project's environmental footprint, conserve resources, and lower pollution. [30], [31] highlight that sustainable practices also enhance social sustainability by creating healthier environments and promoting renewable resources. Moreover, project sustainability is now a competitive advantage, as governments and clients increasingly prioritize projects meeting sustainability standards, such as LEED or BREEAM certifications, helping construction companies attract environmentally conscious clients and strengthen their market position.

2.5 Research Gap

Despite the growing body of literature on sustainable construction practices, there is still a lack of empirical studies that focus specifically on the Indonesian context, particularly in rapidly developing regions such as Karawang. While much of the existing research has focused on the environmental benefits of sustainable materials and waste management, fewer studies have explored their combined effects on cost efficiency and project sustainability. This study seeks to address this gap by examining the specific factors influencing construction project outcomes in Karawang, Indonesia, through the lens of sustainable practices and quantitative analysis.

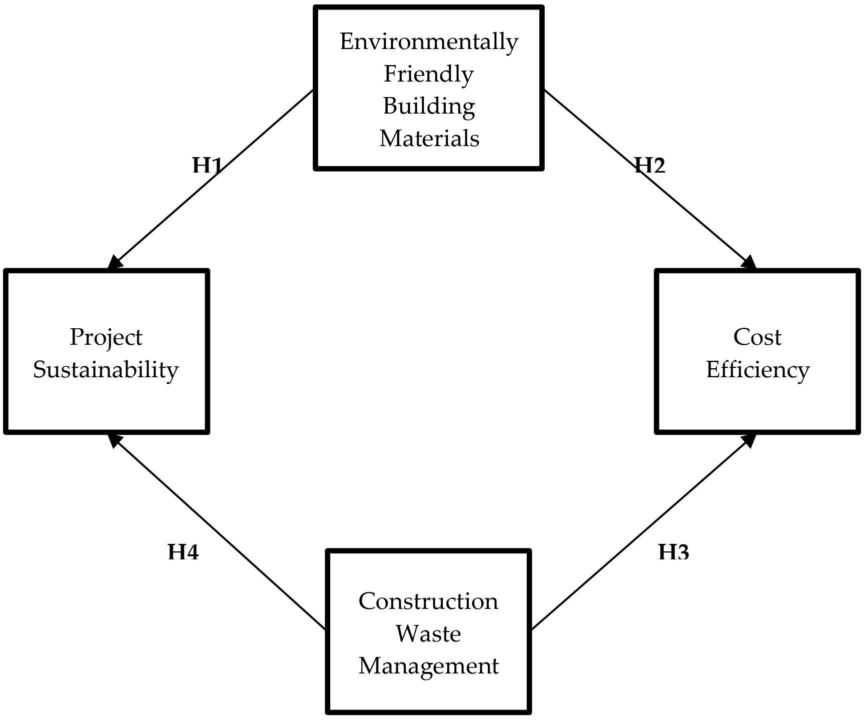

Figure 1. Conceptual Framework

3. METHODS

3.1 Research Design

The research adopted a quantitative design to quantify the relationships between the independent variables (use of environmentally friendly building materials and construction waste management) and the dependent variables (cost efficiency and project sustainability). A cross-sectional survey was conducted to collect data from construction professionals, project managers, contractors, and other stakeholders in the construction industry in Karawang, making it suitable for analyzing large samples and providing statistical evidence of cause-and-effect relationships. The target population consisted of professionals involved in construction projects in Karawang, and a purposive sample of 150 respondents was selected, ensuring participants had relevant experience in sustainable construction practices. This sample size was appropriate for SEM-PLS analysis, which is well-suited for small to medium samples and provides sufficient statistical power to detect significant relationships. The sample included a diverse range of participants, such as project managers, site engineers, procurement officers, and construction supervisors, all of whom had at least two years of experience in managing or overseeing construction projects involving environmentally friendly materials or waste management practices, ensuring the data collected was based on informed opinions and experiences.

3.2 Data Collection Instrument

Data was collected using a structured questionnaire designed to measure the use of environmentally friendly building materials, construction waste management practices, cost efficiency, and project sustainability. The questionnaire was divided into four sections, each corresponding to one of the variables, with each item rated on a 5-point Likert scale, where 1 represented "strongly disagree" and 5 represented "strongly agree." This Likert scale format, widely used in social science research, is effective for capturing the intensity of respondents' attitudes and perceptions regarding the variables.

3.3 Data Analysis Method

The questionnaire data were analyzed using Structural Equation Modeling-Partial Least Squares (SEM-PLS 3), a technique suited for examining complex relationships between multiple variables, particularly with smaller samples. SEM-PLS is ideal for exploring latent constructs and handling models that may not meet the assumptions of other techniques. The analysis started with a measurement model to assess construct reliability and validity, using Average Variance Extracted (AVE) for convergent validity and the Fornell-Larcker criterion for discriminant validity. Reliability was confirmed with Cronbach's alpha and composite reliability, both requiring values above 0.7. After validating the measurement model, the structural model was used to examine relationships between the independent (environmentally friendly building materials and construction waste management) and dependent variables (cost efficiency and project sustainability). Path coefficients and bootstrapping were used to evaluate statistical significance, while the coefficient of determination (R^2) measured the model's explanatory power.

4. RESULTS AND DISCUSSION

4.1 Descriptive Statistics

The descriptive statistics provide an overview of the demographic characteristics of the 150 respondents involved in construction projects in Karawang, as well as their responses to key variables: the use of environmentally friendly building materials, construction waste management, cost efficiency, and project sustainability. The majority of respondents were male (78%), with 22% female, holding roles such as project managers (30%), site engineers (37%), procurement officers (20%), and construction supervisors (13%), and averaging 8.3 years of experience. The use of environmentally friendly materials had a mean score of 4.21, with 40% strongly agreeing that such materials were used. For construction waste management, the mean score was 4.33, with 43% strongly agreeing that recycling and disposal practices were implemented. Cost efficiency was rated positively, with a mean of 4.15, as 37% strongly agreed that sustainable practices reduced costs. Project sustainability received the highest mean score of 4.40, with 47% strongly agreeing that their projects were sustainable in terms of environmental, social, and economic impacts.

4.2 Measurement Model Evaluation

The evaluation of the measurement model is critical for assessing the reliability and validity of the constructs used in the study. This section discusses the results of the measurement model based on key indicators such as loading factors, Cronbach’s alpha, composite reliability, and Average Variance Extracted (AVE). These metrics provide insights into the internal consistency, convergent validity, and reliability of the constructs: Environmentally Friendly Building Materials, Construction Waste Management, Cost Efficiency, and Project Sustainability.

Table 1. Measurement Model Assessment

Variable	Code	Loading Factor	Cronbach's Alpha	Composite Reliability	Average Variant Extracted
Environmentally Friendly Building Materials	EFB.1	0.845	0.885	0.928	0.812
	EFB.2	0.939			
	EFB.3	0.916			
Construction Waste Management	CWM.1	0.759	0.767	0.866	0.684
	CWM.2	0.889			
	CWM.3	0.829			
Cost Efficiency	CEF.1	0.812	0.850	0.898	0.687
	CEF.2	0.834			
	CEF.3	0.848			
	CEF.4	0.822			
Project Sustainability	PST.1	0.841	0.876	0.910	0.668
	PST.2	0.807			
	PST.3	0.807			
	PST.4	0.823			
	PST.5	0.809			

Source: Data Processing Results (2024)

The measurement model evaluation confirmed that all constructs—Environmentally Friendly Building Materials (EFB), Construction Waste Management (CWM), Cost Efficiency (CEF), and Project Sustainability (PST)—demonstrated high reliability and validity. Each construct had loading factors above 0.70, with Cronbach's alpha, composite reliability (CR), and Average Variance Extracted (AVE) values exceeding recommended thresholds, ensuring strong internal consistency and convergent validity. These results provide confidence for the subsequent analysis of the relationships between the key variables in the study.

4.3 Discriminant Validity Evaluation

Discriminant validity refers to the extent to which a construct is distinct from other constructs within the model. In this study, it was assessed using the Fornell-Larcker criterion, which compares the square root of the Average Variance Extracted (AVE) for each construct with the correlations between constructs. Discriminant validity is established when the square root of the AVE for a construct is greater than its correlations with other constructs in the model. The results of this assessment are presented in a table, where the diagonal values (in bold) represent the square root of the AVE for each construct.

Table 2. Discriminant Validity

	Construction Waste Management	Cost Efficiency	Environmentally Friendly Building Materials	Project Sustainability
Construction Waste Management	0.827			
Cost Efficiency	0.628	0.829		
Environmentally Friendly Building Materials	0.302	0.254	0.801	
Project Sustainability	0.673	0.818	0.272	0.818

Source: Data Processing Results (2024)

The square root of the AVE for Construction Waste Management (0.827) exceeds its correlations with other constructs, confirming discriminant validity. Similarly, Cost Efficiency (AVE 0.829) shows higher discriminant validity, despite its strong relationship with Project Sustainability. Environmentally Friendly Building Materials (AVE 0.801) and Project Sustainability (AVE 0.818) also demonstrate discriminant validity, with AVE values greater than their correlations with other constructs. Overall, the Fornell-Larcker criterion confirms that all constructs in the model have satisfactory discriminant validity.

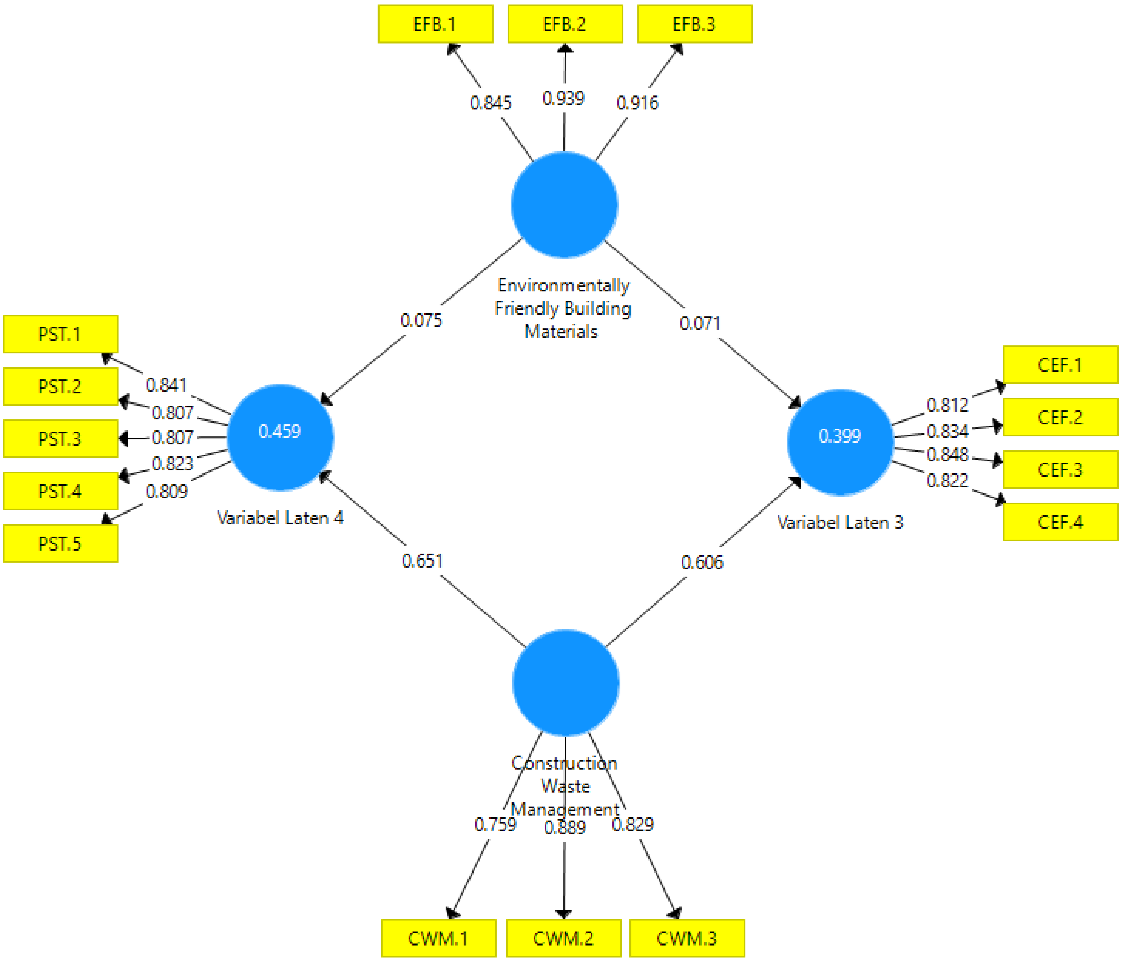

Figure 1. Model Results
Source: Data Processed by Researchers, 2024

4.4 Model Fit Evaluation

Assessing the model fit is crucial in determining how well the hypothesized model aligns with the observed data. Various fit indices, such as the Standardized Root Mean Square Residual (SRMR), d_ULS, d_G, Chi-Square, and Normed Fit Index (NFI), are used to evaluate the adequacy of the model. This section discusses the model fit indices for both the saturated and estimated models to assess how well the measurement and structural models fit the data.

Table 3. Model Fit Results Test

	Saturated Model	Estimated Model
SRMR	0.076	0.133
d_ULS	0.688	2.118
d_G	0.405	0.573
Chi-Square	269.824	332.891

NFI	0.773	0.720

Source: Process Data Analysis (2024)

The Standardized Root Mean Square Residual (SRMR) measures the discrepancy between observed and predicted correlations, with values below 0.08 indicating a good fit. The saturated model's SRMR is 0.076, meeting the threshold, while the estimated model's SRMR is 0.133, indicating room for improvement. Similarly, the d_ULS and d_G values, which assess the fit of PLS-SEM models, show that the saturated model fits better than the estimated model. The Chi-Square statistic, which evaluates the discrepancy between expected and observed covariance matrices, is lower for the saturated model (269.824) than for the estimated model (332.891), further indicating that the estimated model needs refinement. The Normed Fit Index (NFI) compares the Chi-Square of the model to a null model, with values above 0.90 suggesting a good fit. However, both the saturated (0.773) and estimated models (0.720) fall short of this threshold, indicating that the structural model requires further adjustments to achieve a better overall fit.

Table 4. Coefficient Model

	R Square	Q2
Cost Efficiency	0.499	0.489
Project Sustainability	0.459	0.449

Source: Data Processing Results (2024)

The R-Square (R^2) value shows the proportion of variance in a dependent variable explained by the independent variables, with values above 0.5 considered moderate to strong in social sciences. The Predictive Relevance (Q^2), assessed through blindfolding, indicates how well the model predicts outcomes. For Cost Efficiency, the R^2 is 0.499, with a Q^2 of 0.489, showing strong explanatory and predictive power. For Project Sustainability, the R^2 is 0.459, and the Q^2 is 0.449, also indicating strong predictive relevance. The close alignment of R^2 and Q^2 values confirms the model's reliability in explaining and predicting both outcomes.

4.5 Hypothesis Testing

The path coefficients, standard deviations, t-statistics, and p-values from the Structural Equation Modeling-Partial Least Squares (SEM-PLS) analysis are used to determine whether the hypothesized relationships are statistically significant. A p-value of less than 0.05 is considered statistically significant, indicating strong support for the proposed hypotheses.

Table 5. Hypothesis Testing

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics	P Values
Construction Waste Management -> Cost Efficiency	0.606	0.614	0.057	10.611	0.000
Construction Waste Management -> Project Sustainability	0.651	0.654	0.061	10.671	0.000
Environmentally Friendly Building Materials -> Cost Efficiency	0.371	0.373	0.067	3.055	0.000
Environmentally Friendly Building Materials -> Project Sustainability	0.475	0.476	0.065	6.165	0.000

Source: Process Data Analysis (2024)

The hypothesis testing results indicate that all four hypotheses were supported, with significant relationships between construction waste management, environmentally friendly building materials, cost efficiency, and project sustainability. For Hypothesis 1, the path coefficient between construction waste management and cost efficiency was 0.606, with a t-statistic of 10.611 and a p-value of 0.000, showing a strong positive relationship. Hypothesis 2 showed a similar result, with a path coefficient of 0.651, t-statistic of 10.671, and p-value of 0.000, confirming the positive impact of waste management on project sustainability. Hypothesis 3 demonstrated a moderate positive relationship between environmentally friendly building materials and cost efficiency, with a path coefficient of 0.371, t-statistic of 3.055, and p-value of 0.000. Finally, Hypothesis 4 confirmed a strong positive relationship between environmentally friendly building materials and project sustainability, with a path coefficient of 0.475, t-statistic of 6.165, and p-value of 0.000. These results highlight the importance of sustainable practices in improving both cost efficiency and project sustainability.

Discussion

The Role of Construction Waste Management in Cost Efficiency and Project Sustainability

The study highlights the significant positive impact of construction waste management on both cost efficiency and project sustainability. The path coefficient between Construction Waste Management and Cost Efficiency was 0.606, with a t-statistic of 10.611 and a p-value of 0.000, indicating a strong, statistically significant relationship, consistent with previous studies such as [19], [20], which emphasize the cost-saving potential of waste reduction strategies like recycling and material reuse. Waste management reduces disposal and replacement costs, enabling more efficient resource allocation, which is crucial in construction projects where waste often drives inefficiencies and financial strain. Effective waste management not only lowers operating costs but also adheres to environmental regulations, reducing ecological footprints. The strong relationship between Construction Waste Management and Project Sustainability (path coefficient = 0.651, t-statistic = 10.671, p-value = 0.000) underscores its role in promoting long-term sustainability by conserving resources and minimizing pollution. These findings align with sustainable construction literature, such as [7], [21], and suggest that construction companies should prioritize waste management plans with specific targets for reduction, recycling, and material reuse to enhance project outcomes, reputation, and competitiveness in a sustainability-focused market.

The Influence of Environmentally Friendly Building Materials on Cost Efficiency and Project Sustainability

The adoption of environmentally friendly building materials has a significant impact on both cost efficiency and project sustainability. The path coefficient between Environmentally Friendly Building Materials and Cost Efficiency was 0.371, with a t-statistic of 3.055 and a p-value of 0.000, indicating a moderate but meaningful positive relationship. While sustainable materials often come with higher initial costs, they lead to long-term savings through improved energy efficiency, reduced maintenance, and increased durability [6], [14], [15]. This aligns with previous research, which shows that materials like recycled steel, bamboo, and low-VOC paints lower lifecycle costs despite higher upfront investments. In Karawang's construction projects, these savings are particularly beneficial for achieving financial efficiency and sustainability goals. Additionally, the path coefficient between Environmentally Friendly Building Materials and Project Sustainability was 0.475, with a t-statistic of 6.165 and a p-value of 0.000, confirming a strong positive relationship. Eco-friendly materials reduce environmental impacts by lowering carbon emissions, reducing resource depletion, and improving indoor environmental quality, supporting the findings of [16]–[18]. These results suggest that construction firms should prioritize sustainable materials, and policymakers can further encourage their use through incentives like tax breaks or subsidies to make green materials more accessible and cost-effective.

Integration of Findings and Practical Implications

The results of this study provide strong evidence that both construction waste management and environmentally friendly building materials are crucial for achieving cost-efficient and sustainable construction projects. The statistically significant relationships between these practices and key outcomes, such as cost efficiency and project sustainability, highlight the importance of integrating sustainability into construction management. A key takeaway is that sustainability and cost efficiency are complementary, as sustainable practices often lead to improved financial performance, challenging the traditional view that sustainability is costly. For construction companies in Karawang and other rapidly developing areas, these findings emphasize the need to incorporate sustainability into project planning and execution. By adopting green materials and waste management strategies, firms can reduce their environmental impact while enhancing their financial performance, contributing to the long-term success and sustainability of their projects and meeting the rising demand for eco-friendly construction solutions.

Future Research Directions

While this study offers valuable insights into the impact of sustainable practices on construction project outcomes, several areas for future research remain. Future studies could include additional variables, such as government regulations, market conditions, and stakeholder engagement, to provide a more comprehensive understanding of the factors influencing cost efficiency and project sustainability. Research could also examine the role of emerging technologies like Building Information Modeling (BIM) and digital tools, which could further enhance the effectiveness of sustainable practices by optimizing resource use and improving project coordination. Expanding the geographic scope of this research to other regions with varying economic and environmental conditions would help generalize the findings and provide broader recommendations for construction firms and policymakers.

5. CONCLUSION

This study confirms that the use of environmentally friendly building materials and effective construction waste management practices are critical for achieving cost efficiency and project sustainability in construction projects. Both practices were found to significantly influence the outcomes, with construction waste management showing a stronger positive impact. These findings highlight that sustainability and cost efficiency can go hand in hand, providing long-term benefits for construction firms. Implementing waste management strategies and adopting green materials not only reduce environmental impacts but also contribute to financial savings through enhanced resource efficiency. The study’s insights offer practical implications for construction companies in Karawang and other regions aiming to balance economic and environmental priorities. Further research could explore additional factors and technologies that influence sustainable construction practices to broaden the scope of this study’s conclusions.

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