Istraživanja i projektovanja za privredu
ISSN 1451-4117
DOI:10.5937/jaes0-55779
www.engineeringscience.rs

Journal of Applied Engineering Science
Original Scientific Paper,
Volume 23, Number 2, Year 2025,
No 1274, pp 303-313

WASTE MATERIAL IN CONSTRUCTION PROJECTS: ANALYZING COST, SCHEDULE, AND ENVIRONMENTAL IMPACTS

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The construction industry is a major contributor to waste generation, leading to increased project costs, schedule delays, and negative environmental impacts. This study examines the causes and effects of waste material in construction projects, focusing on project planning, material quality, and storage practices as critical factors impacting cost overruns, project delays, and environmental sustainability. Using Partial Least Squares Structural Equation Modeling (PLS-SEM), this research analyzes the relationships between waste-related factors and their direct impacts on project performance. Data were gathered from 141 respondents working on various PT XYZ projects, with validation from 12 industry experts. Findings reveal that deficiencies in project planning and poor material quality are primary contributors to waste, leading to substantial cost increases, timeline extensions, and environmental harm. Additionally, inadequate storage practices exacerbate waste issues by causing material damage, loss, and higher disposal costs. The study recommends that construction project managers implement comprehensive planning, enforce strict quality standards, and optimize storage management to effectively reduce waste. These insights provide practical guidance for improving cost control, ensuring timely project completion, and advancing sustainable practices within the construction sector, ultimately promoting a more efficient and environmentally responsible approach to project management.

Keywords: construction waste, project planning, material quality, storage management, environmental impact

HIGHLIGHTS

- Identifies project planning and material quality as key waste contributors in construction projects.
- Applies PLS-SEM to model causal relationships between waste factors and project performance.
- Reveals that poor planning and substandard materials significantly increase costs and delays.
- Offers practical strategies to reduce waste through planning, quality control, and storage optimization.

1 Introduction

1.1 Preface

Waste material is a significant challenge in construction projects, often contributing to inefficiencies that drive up costs, extend project timelines, and generate negative environmental impacts [1], [2]. In construction settings, waste materials encompass a range of discarded resources, from construction debris and excess materials to damaged supplies, resulting from mismanagement, design changes, and errors in planning [1], [2]. These issues not only undermine project efficiency but also elevate operational costs, lead to additional labor requirements, and demand further investments in waste disposal and management [3], [4]. For a contractor like PT XYZ, a leading player in Indonesia's construction industry, waste material represents a critical factor that directly impacts profitability, reputation, and project sustainability.

Previous studies have identified a variety of factors that contribute to waste generation in construction, including insufficient project planning, inadequate storage facilities, suboptimal material handling, and unforeseen changes in design or specifications [5], [6]. Studies also highlight that a lack of coordination among project teams, as well as ineffective communication, can exacerbate waste issues, leading to resource misallocation and increased material losses [7], [8]. The limited use of advanced technology and environmental awareness also plays a role, as construction companies that lack technological adoption for waste management are more likely to struggle with material inefficiency and high disposal costs [9].

In PT XYZ's construction projects, waste material has emerged as a pressing concern, stemming from diverse factors such as inaccuracies in initial material estimations, logistics mismanagement, and substandard handling of materials on-site. These issues are consistent with global research findings that reveal the negative impacts of waste material on construction projects, particularly regarding increased project costs, delays, and resource depletion [2]. This underscores the importance of identifying the specific factors that contribute to waste material within the construction context, especially in Indonesia, where environmental concerns and resource constraints are prominent [10], [11].

The primary objective of this study is to examine the causes and consequences of waste material in construction projects managed by PT XYZ. Specifically, this research seeks to identify exogenous variables (causal factors) and endogenous variables (resulting impacts) associated with waste generation and material inefficiency. The study employs a structured questionnaire survey distributed to 150 construction practitioners, with 141 responses collected, representing a high response rate. Furthermore, validation is conducted by 12 experts to ensure that the identified variables and indicators are contextually relevant to the construction industry in Indonesia. This expert validation is crucial to refining the study's focus on practical factors that influence material waste in real project scenarios [2].

A quantitative approach is applied in this study, using Partial Least Squares Structural Equation Modeling (PLS-SEM) to analyze the relationships between waste material causes and impacts. PLS-SEM offers a robust analytical framework for exploring complex, multi-variable relationships, providing valuable insights into how specific waste factors influence project outcomes [12], [13]. The findings are anticipated to support the development of more effective waste management strategies in construction, aiming to reduce waste-related inefficiencies, mitigate environmental impacts, and improve overall project performance [9].

1.2 Literature review

1.2.1 Causes of waste material

Waste material generation is a pervasive issue in construction projects, resulting from a wide array of factors that influence project efficiency and sustainability. Research identifies several primary causes of waste material, such as inadequate project planning, poor material handling, and design modifications during project execution [2], [5], [6]. These issues are often compounded by logistical challenges, material storage deficiencies, and improper estimation of material requirements, which collectively contribute to significant material wastage [14]–[16].

In recent years, the construction industry has witnessed significant advancements in material technology aimed at improving performance, reducing consumption, and supporting faster installation [17]. For instance, pre-applied waterproofing membranes are now designed for faster and more secure application, intumescent fireproofing coatings offer enhanced protection with thinner layers, and spray foam thermal insulation enables better coverage with minimal material waste [18]. Similarly, modular acoustic panels are engineered for efficient installation while maintaining high sound absorption [18]. These innovations are intended to optimize the use of materials by minimizing excess, reducing labor time, and maintaining or even exceeding required performance standards [19]–[21].

However, despite these technological improvements, material waste remains a persistent challenge on construction sites [22]. The effectiveness of advanced materials in reducing waste is often undermined by upstream and downstream factors such as inaccurate planning, lack of skilled labor, mishandling during delivery and installation, and insufficient quality control. In practice, the transition from conventional to high-performance materials does not automatically eliminate inefficiencies; instead, it may introduce new complexities that require more precise execution and supervision. Without proper integration between planning, procurement, and site practices, even advanced materials are susceptible to overordering, misapplication, or damage-ultimately contributing to waste[23]–[25].

Specific to the Indonesian context, studies emphasize that weaknesses in project planning-such as insufficient material estimation and lack of logistical foresight-are particularly impactful [26]. Inaccuracies in initial planning can lead to excess or shortage of materials on-site, resulting in either material loss or project delays. Furthermore, logistical challenges, including improper scheduling and coordination for material deliveries, exacerbate the problem, leading to inefficient resource usage [27].

Material quality and availability also play crucial roles in waste generation. According to research, reliance on substandard materials, supply inconsistencies, and dependence on imported materials frequently lead to resource wastage, as unsuitable or delayed materials disrupt the planned workflow [28], [29]. Additionally, inadequate storage facilities and improper material handling procedures can lead to damage or spoilage, further adding to construction waste [30].

1.2.2 Impact of waste material on project performance

The consequences of waste material in construction projects are far-reaching, impacting cost efficiency, project timelines, and environmental sustainability. Studies indicate that waste material significantly drives up project costs due to the need for additional procurement, waste disposal, and rework [31], [32]. Construction projects with high levels of waste often face budget overruns, as unplanned expenses accrue from the disposal of excess materials and additional labor costs associated with managing these inefficiencies [33], [34].

Environmental and reputational impacts are also major concerns, particularly for companies like PT XYZ that operate within regulatory frameworks emphasizing sustainability. Increased material waste not only depletes natural resources but also generates emissions and pollution from disposal activities, posing challenges to both project managers and environmental stakeholders [2]. Additionally, construction waste has been shown to contribute to project delays, as time is required to rectify the issues caused by improper materials handling, reordering, and disposal processes [35], [36].

1.2.3 Strategies for mitigating waste material impacts

Effective waste management strategies are essential to minimizing the adverse impacts of waste material in construction. Key strategies identified in the literature include enhancing project planning processes, improving coordination and communication, and implementing advanced technologies such as Building Information Modeling (BIM). By using BIM, for instance, construction teams can better anticipate material requirements, streamline logistics, and minimize design discrepancies that often lead to waste [37].

Additionally, introducing comprehensive material handling and storage protocols can significantly reduce material damage and wastage. Proper storage solutions, secure on-site handling, and regular material audits are recognized as practical steps in waste reduction [37]. Companies can also enhance workforce training and environmental awareness, promoting practices that align with sustainable resource management and reducing waste at every project stage [37].

2 Materials and methods

2.1 Research design

This study employs a quantitative approach to analyze the causes and impacts of waste material in construction projects managed by PT XYZ. The primary analytical tool used is Partial Least Squares Structural Equation Modeling (PLS-SEM), which is ideal for examining the complex relationships between latent variables. By using PLS-SEM, this study can identify how exogenous variables (e.g., project planning, material handling, storage practices) influence endogenous outcomes (e.g., increased costs, project delays, environmental impact). This method enables a comprehensive exploration of both direct and indirect impacts of waste material on construction project outcomes, facilitating an understanding of underlying causal relationships and potential mitigation strategies.

2.2 Questionnaire survey

Data collection for this study was conducted through a structured questionnaire distributed to 150 practitioners, including project managers involved in PT XYZ's projects. Of these, 141 valid responses were collected, yielding a high response rate of 93%. The questionnaire was designed to capture respondents' insights on both the causes and impacts of waste material in construction projects, utilizing a 6-point Likert scale to assess the significance and frequency of various factors related to waste generation and management.

The indicators for variables X and Y were derived from prior academic studies, providing a reliable foundation with 47 indicators across 18 variables. These indicators were then reviewed and refined by experts, who filtered them down to 13 indicators within 6 variables, deemed most relevant to the context of Indonesia and the operations of PT XYZ. This refined selection formed the basis of the questionnaire, ensuring the study's focus aligns closely with industry practices and challenges specific to construction projects in Indonesia.

2.3 Data collection

The study sample was selected using purposive sampling, targeting practitioners directly involved in construction projects managed by PT XYZ. This approach ensured that the respondents' insights accurately represent the practices and challenges encountered in PT XYZ's project execution, particularly regarding waste material management issues that impact project costs and schedules. The dataset gathered from the survey responses offers a comprehensive understanding of current waste management practices, challenges, and the effects of waste material on project performance. This dataset forms the foundation for subsequent PLS-SEM analysis, aimed at quantifying the impact of waste-related factors on project outcomes.

2.4 Analysis indicators and variables

The study categorizes the indicators and variables into two main groups: causes of waste material (exogenous variables) and impacts of waste material (endogenous variables). The exogenous variables include factors such as project planning deficiencies, material quality issues, and storage practices, while the endogenous variables encompass outcomes such as increased project costs, delays, environmental impacts, and reduced project quality. Tables 1 and 2 summarize the indicators analyzed in each variable category.

Table 1. Exogenous Variables (Causes of waste material) and Indicators

No	Exogenous Variables (Causes of waste material)	Indicators
X.1	Project Planning	X1.1 Weakness in material needs estimation
		X1.2 Insufficient logistics planning
		X1.3 Design changes during the project
X.2	Execution and Management	X2.1 Errors in work methods
		X2.2 Inadequate supervision and management
X.3	Material Quality	X3.1 Non-standard material quality
		X3.2 Limited availability of materials in the local market
X.4	Material Storage	X4.2 Loss of materials due to insecure storage
		X4.3 Material damage due to improper storage

Table 2. Endogenous Variables (Impacts of waste material) and Indicators

No	Endogenous Variables (Impacts of waste material)	Indicators
Y.1	Project Cost Increase	Y1.1 Increase in material costs
		Y1.3 Additional costs due to material damage or surplus
Y.2	Project Completion Delay	Y2.1 Extra time for repairs due to material damage
		Y2.2 Delay in re-supplying wasted materials

2.5 Exploratory Factor Analysis (EFA)

Exploratory Factor Analysis (EFA) was used to identify the key factors contributing to waste material in construction. This analysis simplifies the dataset by grouping highly correlated variables, making it easier to identify primary factors impacting waste material generation. A loading factor threshold of 0.5 was set to ensure that only significant relationships are considered [38], [39]. The Scree plot and eigenvalue criteria were also applied to determine the optimal number of factors for the model.

2.6 Partial Least Squares Structural Equation Modeling (PLS-SEM)

PLS-SEM was applied to model the relationships between latent variables that cannot be directly observed, using validated indicators. This approach enables the testing of hypotheses regarding the relationships between waste material causes and their impacts on project performance. The PLS-SEM analysis was conducted in three main stages:

- Inner and Outer Model: This involves assessing R-squared values, Goodness of Fit, discriminant validity, and the outer loading of each indicator to ensure model adequacy.
- Bootstrapping: Hypothesis testing is conducted through bootstrapping to evaluate the statistical significance of relationships between variables.
- Prediction: The PLS results are used to predict the impact of waste material causes on project outcomes such as costs, delays, and environmental impact.

2.7 Model assessment

The model's reliability and validity were tested using several metrics, including Cronbach's Alpha and Composite Reliability (CR). CR values above 0.7 indicate high reliability, while convergent validity was measured using Average Variance Extracted (AVE), which should exceed 0.5 to confirm that the constructs are adequately represented by their indicators [40], [41]. These assessments validate the model's capacity to effectively analyze the impact of waste material factors on PT XYZ's construction projects.

3 Results and discussion

3.1 Results

This section presents the results of analyzing the factors contributing to waste material and their impacts on construction projects managed by PT XYZ. The analysis uses Partial Least Squares Structural Equation Modeling (PLS-SEM) to explore relationships between the causes and consequences of waste material, focusing on outcomes such as increased costs, project delays, and environmental impacts.

3.1.1 Model validity and reliability

The initial step in the PLS-SEM analysis evaluates the model's validity and reliability using metrics such as Composite Reliability (CR), Average Variance Extracted (AVE), and Cronbach's Alpha (Cα). These indicators ensure that the model reliably measures the latent variables associated with waste material causes and impacts.

Table 3. Composite Reliability, Cronbach's Alpha, and AVE

Indicator	Cronbach's Alpha	Composite Reliability	AVE
X1 (Project Planning)	0,632	0,803	0,578
X2 (Execution and Management)	0,136	0,688	0,534
X3 (Material Quality)	0,529	0,809	0,679
X4 (Material Storage)	0,720	0,877	0,781
Y1 (Increased Costs)	0,415	0,770	0,628
Y2 (Project Delays)	0,563	0,817	0,691

High Composite Reliability values for constructs X1, X3, X4, Y1, and Y2 confirm that the model is both reliable and valid. The AVE values above 0.50 for each construct indicate that these latent variables are well represented by their respective indicators, supporting construct validity.

3.1.2 Impact of waste material on cost increases and project delays

The relationship between waste material causes and their impact on costs and delays was tested using path coefficients in PLS-SEM. The findings indicate that factors such as project planning, material quality, and storage practices significantly influence both cost increases and project delays.

Table 4. Path Coefficients and T-Statistics

Path	Original Sample (O)	T-Statistics	P-Values
X1 → Y1	0,280	2,864	0,004
X1 → Y2	0,245	2,150	0,032
X2 → Y1	-0,045	0,490	0,624
X2 → Y2	-0,103	1,048	0,295
X3 → Y1	0,274	2,525	0,012
X3 → Y2	0,297	2,941	0,003
X4 → Y1	0,181	1,743	0,081
X4 → Y2	0,148	1,492	0,136

The results confirm the significant role of project planning (X1) and material quality (X3) in contributing to cost overruns (Y1) and project delays (Y2), as indicated by P-values below 0.05. Although the effects of execution and management (X2) and material storage (X4) on cost and delays were observed, they were not statistically significant.

3.1.3 Structural model of relationships

This model depicts the hypothesized relationships among the key latent variables, and is constructed based on a comprehensive literature review and expert validation. Each exogenous variable is linked to the two endogenous outcomes (Y1 and Y2), representing project cost increase and project completion delay.

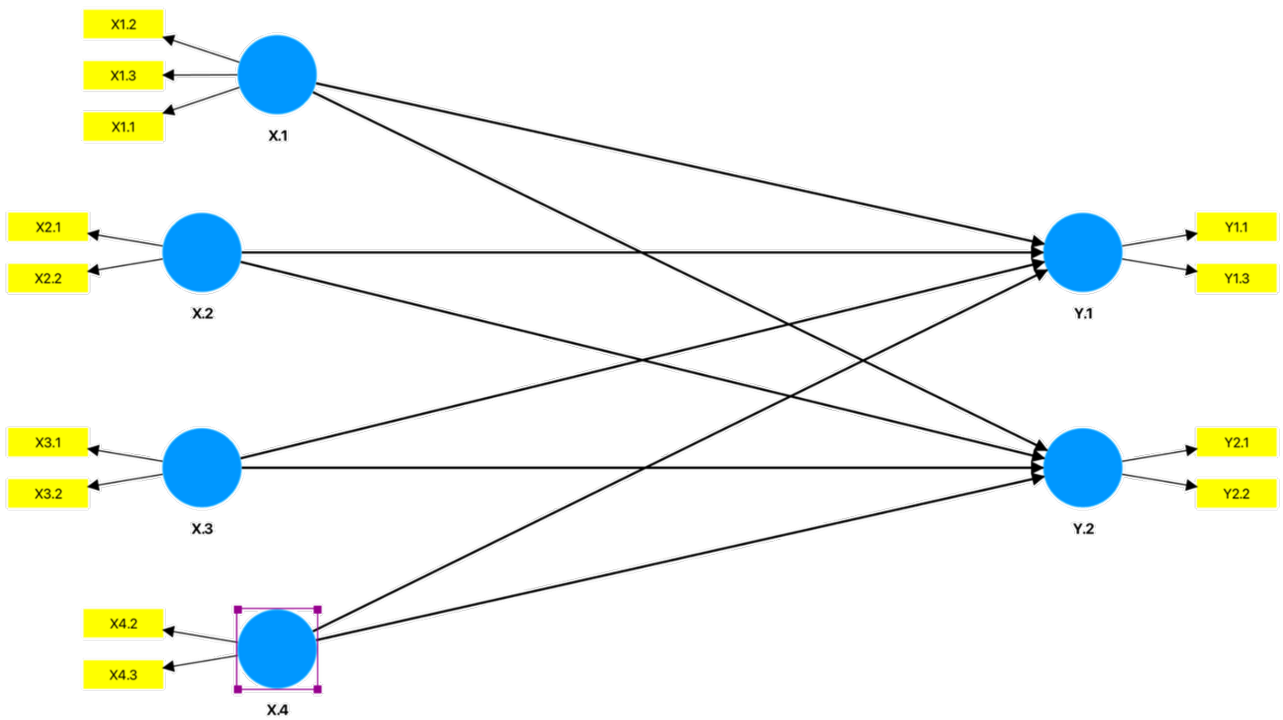

Fig. 1. Structural Model: Waste material causes and impacts

The structure reflects a reflective measurement model, where each indicator is assumed to be caused by its corresponding construct. This is consistent with the nature of latent variables in behavioral research and aligns with the modeling logic of PLS-SEM.

3.1.4 Path coefficient analysis

Path coefficient analysis in PLS-SEM provides insights into the strength of the relationships between variables. This analysis helps in understanding the extent to which each cause of waste material influences project outcomes.

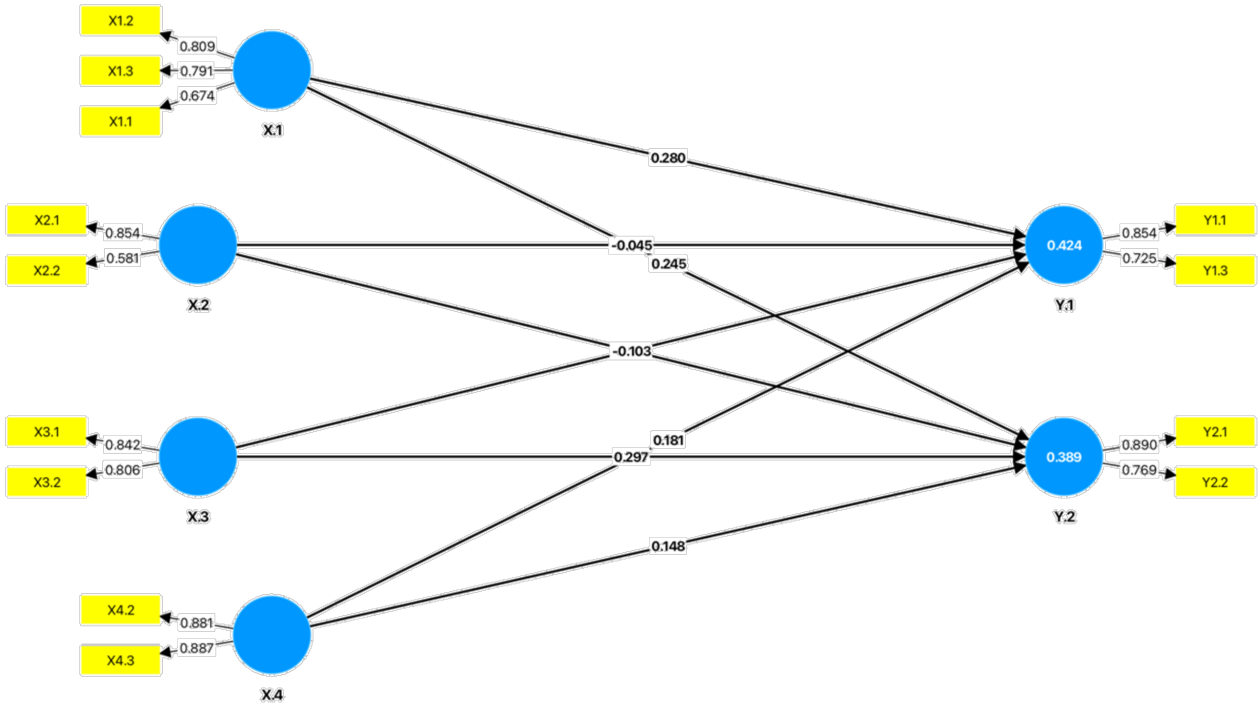

Fig. 2. Path coefficients and outer loadings

The path coefficients reveal that exogenous variables X1 (Project Planning) and X3 (Material Quality) have a stronger influence on endogenous variables Y1 (Cost Increases) and Y2 (Project Delays) compared to X2 (Execution and Management) and X4 (Material Storage).

3.1.5 Hypothesis testing and significance of paths

Hypothesis testing was conducted to assess the significance of relationships between exogenous and endogenous variables, utilizing T-statistics and P-values.

Table 5. Summary of Hypothesis Testing

Hypothesis	Path Coefficient	T-statistic	P-value	Conclusion
H1: X1 → Y1	0,280	2,864	0,004	Accepted
H2: X1 → Y2	0,245	2,150	0,032	Accepted
H3: X2 → Y1	-0,045	0,490	0,624	Rejected
H4: X2 → Y2	-0,103	1,048	0,295	Rejected
H5: X3 → Y1	0,274	2,525	0,012	Accepted
H6: X3 → Y2	0,297	2,941	0,003	Accepted
H7: X4 → Y1	0,181	1,743	0,081	Rejected
H8: X4 → Y2	0,148	1,492	0,136	Rejected

All hypotheses related to project planning (X1) and material quality (X3) significantly impacting cost increases and delays were accepted, indicating their substantial influence on project outcomes. Hypotheses related to execution and management (X2) and material storage (X4) did not achieve statistical significance.

3.1.6 Model fit evaluation

The model's goodness of fit was evaluated using the Standardized Root Mean Square Residual (SRMR), with a value of 0.101, which exceeds the 0.08 threshold, indicating a marginal fit.

Table 6. Goodness of Fit (GOF) Indicators

GOF Indicator	Saturated Model	Estimated Model
SRMR	0,101	0,101

Although the SRMR value exceeds the commonly accepted threshold of 0.08, it remains within an acceptable range for exploratory studies. The model still demonstrates practical utility in explaining the relationships between variables.

3.1.7 Significance of paths by P-value

The visualization below presents the P-values for each path between latent variables in the structural model, highlighting paths that are statistically significant.

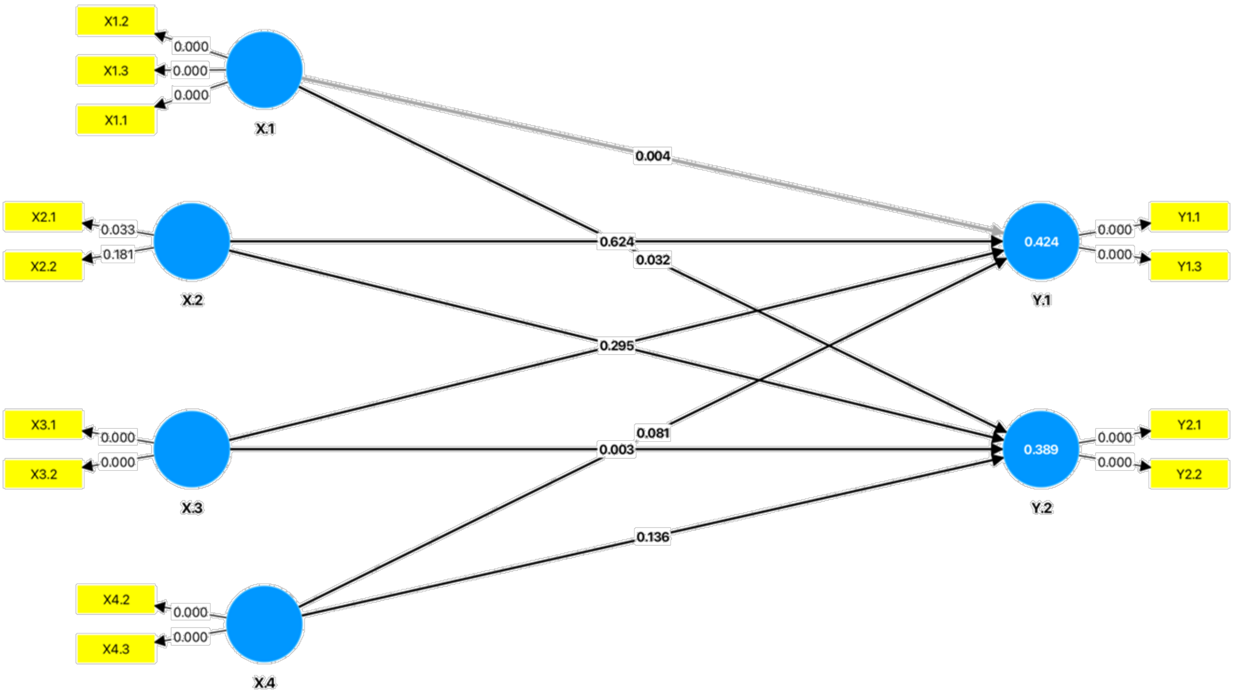

Fig. 3. Significance levels (P-Values) in the structural model

Paths with P-values below 0.05 indicate significant relationships between latent variables, underscoring the strong influence of project planning and material quality on both cost increases and project delays.

3.2 Discussion

This study examines the impact of waste material on cost increases, project delays, and environmental consequences in construction projects managed by PT XYZ. Using Partial Least Squares Structural Equation Modeling (PLS-SEM), it investigates the relationships between primary causes of material waste and their effects on project performance. The results confirm that project planning and material quality are statistically significant factors that influence the overall efficiency of a construction project. These findings provide a reliable empirical foundation for prioritizing improvement strategies in early project phases.

In contrast, factors related to execution and management (X2) and material storage (X4) do not exhibit a significant impact in this context. Although these dimensions may intuitively seem important, their influence may be mediated or dependent on other variables not captured in the current model, such as contractor behavior or implementation stage coordination.

3.2.1 Key influences on project costs and delays

- Project Planning (X1): Analysis reveals that deficiencies in project planning, such as inaccurate material estimates and insufficient logistics, have a significant impact on cost escalation (Y1) and project delays (Y2). Path coefficients ($X1 \rightarrow Y1 = 0.280$; $X1 \rightarrow Y2 = 0.245$) indicate that poor planning leads to excessive material use, mismanagement, and unnecessary rework, cumulatively inflating costs and extending project timelines. These findings align with prior research highlighting the importance of detailed planning in mitigating inefficiencies and waste [42], [43]. This result supports the notion that early-phase decision-making has the most leverage on overall material efficiency and should be treated as a strategic priority by project stakeholders.
- Material Quality (X3): Material quality is shown to substantially affect project outcomes, particularly when substandard or incompatible materials are used. Results ($X3 \rightarrow Y1 = 0.274$; $X3 \rightarrow Y2 = 0.297$) suggest that low-quality materials necessitate additional procurement and rework, directly impacting project budgets and schedules. This supports existing research linking poor material quality to waste generation and increased project costs [44], [45]. This also highlights the importance of supplier control and product testing as essential components of quality assurance in material procurement strategies.

3.2.2 Practical implications for project management

The findings offer several practical insights for project managers in construction, particularly for large-scale projects:

- Enhancing Planning and Estimation Processes: Accurate material estimation and logistical planning are essential for reducing waste. Project managers should adopt comprehensive planning practices, including advanced tools like Building Information Modeling (BIM), which can enhance estimation accuracy and visibility, minimizing unnecessary waste [46], [47]. Moreover, integrating simulation and scenario-based planning in the pre-construction phase can allow stakeholders to test alternative supply strategies and avoid material misalignment.
- Implementing Material Quality Standards: Material quality control should be prioritized to prevent project disruptions and cost increases due to poor-quality materials. Rigorous quality checks and defined supplier selection criteria can help reduce the use of incompatible or substandard materials [48], [49]. Developing long-term relationships with certified suppliers and introducing material benchmarking systems may further enhance quality consistency.

3.2.3 Broader impact of waste material in construction

The negative impacts of waste material extend beyond project costs and timelines, influencing environmental sustainability and organizational reputation:

- Environmental Impact: Waste material contributes to environmental degradation through increased construction waste and emissions from disposal activities. Effective waste reduction strategies can reduce the environmental footprint of construction activities, promoting sustainable practices that comply with regulatory standards [50], [51]. With increasing ESG (Environmental, Social, and Governance) requirements globally, organizations that fail to address material waste risk non-compliance with green certifications and environmental law.
- Cost and Resource Efficiency: The financial burden of waste management, including additional procurement, disposal costs, and rework, strains project budgets and reduces profitability. Addressing waste causes at the planning stage can help contractors achieve greater cost efficiency, yielding long-term benefits for profitability and resource conservation [52], [53]. This also leads to more predictable project performance metrics and enhances the competitiveness of firms in tender evaluations.

3.2.4 Limitations and future research directions

Several limitations of this study should be noted. The dataset focuses exclusively on projects managed by PT XYZ, which may limit the generalizability of findings to other construction contexts, especially in regions with different regulatory frameworks or market conditions. Additionally, while this study concentrates on project planning, material quality, and storage practices as primary waste material causes, other influential factors, such as contractor expertise and labor productivity, may also play a significant role and merit further investigation.

Furthermore, the current model does not evaluate the interaction effects between the exogenous variables (e.g., how poor planning may exacerbate the impact of low-quality materials), which may offer deeper insight into systemic inefficiencies.

Future research could expand this model by incorporating additional variables, such as contractor performance metrics, labor productivity, and external economic factors. Investigating waste management practices across a broader range of construction firms and project types could yield insights into best practices for minimizing waste material and optimizing resource usage in diverse construction environments.

4 Conclusions

This study identifies the causes and impacts of material waste in construction projects, focusing on cost overruns, project delays, and environmental impacts through Partial Least Squares Structural Equation Modeling (PLS-SEM). By analyzing key variables related to project planning, material quality, and storage practices, the study provides several critical insights:

The results reveal that deficiencies in project planning (X1) are among the most significant contributors to waste material, impacting both cost increases (Y1) and project delays (Y2). Poor planning often results in over-ordering, inefficient resource allocation, and rework, collectively driving up project costs and extending timelines. These findings underscore the necessity for comprehensive and precise planning to mitigate material waste and improve project efficiency.

Material quality (X3) also plays a crucial role; low-quality or incompatible materials substantially increase costs and cause delays. The analysis indicates that inadequate material quality necessitates additional procurement and rework, directly impacting project budgets and schedules. Enforcing strict quality control measures can help reduce these negative impacts by minimizing waste generation.

To address these root causes of waste material, this study recommends that project managers adopt robust planning strategies, enforce stringent quality control standards, and optimize storage practices. Implementing these strategies can help construction firms reduce waste, lower environmental impacts, enhance project efficiency, and control costs.

This research contributes valuable insights into waste material management within construction projects and highlights the importance of improved practices to minimize resource waste. Future studies should consider additional factors, such as contractor expertise, labor productivity, and economic conditions, to develop a more comprehensive model of waste management in construction. Expanding this research to different types of projects and regulatory environments may further enhance understanding and establish best practices for waste reduction.

5 Acknowledgement

The author would like to express his deepest gratitude to all those who have supported him during this research.

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7 Conflict of interest statement

The authors declare that there is no conflict of interest regarding the publication of this paper.

8 Author contributions

Jatiaryo Sidiq Ramadhan: Conceptualization, methodology, formal analysis, writing - original draft preparation. Michael Limanow: Investigation, data curation. Muhammad Ryan Putra Raflyanto: Writing - review & editing, visualization, project administration. Tota Pirdo Kasih: Supervision, validation.

9 Availability statement

The analysis supporting data are available at https://zenodo.org/records/15481817

10 Supplementary materials

No supplementary materials are included in this manuscript.

Paper submitted: 31.12.2024.
Paper accepted: 20.05.2025.