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Analysis of Construction Material Waste in a Four-Storey Office Shop Building Project

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Abstract

The construction industry has experienced rapid growth in recent years, as evidenced by the development of roads, bridges, residential buildings, multi-storey structures such as apartments, offices, shopping centres, and other infrastructure projects. Material costs play a crucial role in determining the success of construction projects. This study employs a quantitative research approach, utilizing primary data gathered through questionnaires distributed directly to 30 on-site respondentsThe responses were analysed using SPSS to identify the factors contributing to material waste during construction. Secondary data, including project cost estimates (Budget Estimate Plan), daily reports, and material purchase records, were also analysed. The study identifies three key factors contributing to material waste: inaccurate on-site measurements, leading to the overestimation of material volumes; complex design changes; and errors in the design during the construction phase. To minimise material waste, the study applies the waste hierarchy concept. The primary types of material waste identified were concrete, bricks, and reinforcing steel. Preventive measures suggested include improving the accuracy of material estimates and orders, tracking materials that can be reused or recycled, and repurposing leftover materials for other functions.

1. Background

The construction industry has experienced rapid development in the modern era, driven by increasing demand for infrastructure such as roads, bridges, residential buildings, and multi-storey structures, including apartments, offices, shopping centres, and other buildings. As urbanisation continues to expand globally, the construction industry plays a pivotal role in shaping the modern environment. However, one of the critical challenges faced by the industry is material waste, which has significant environmental, economic, and social implications.

Material costs are one of the most substantial components of a construction project's total budget. The material cost can contribute up to 40-60% of the total project cost, making it one of the most influential factors in determining the project's financial viability. Efficient material management is vital to minimising waste, ensuring that only the necessary amount of material is ordered and used. However, it is nearly impossible to avoid material waste entirely during construction due to various factors, including inaccuracies in measurement, design changes, and unforeseen site conditions. Studies have found that around 75% of construction materials end up as waste, with significant portions of this waste being avoidable through better planning, handling, and recycling [1].

The primary aim of this research is to identify the key factors that contribute to material waste on construction sites, particularly in the construction of a 4-storey office building. The study uses a quantitative research methodology, which focuses on collecting numerical data through surveys distributed to field respondents. This approach is effective for identifying patterns and correlations between variables that contribute to material waste. [2] describes quantitative research as grounded in positivism, where data is represented numerically and analysed using statistical methods to draw conclusions. By applying this method, the study aims to quantify the amount of waste generated, identify the root causes, and propose effective waste reduction strategies.

Additionally, the study incorporates secondary data, such as project cost estimates (RAB), daily progress reports, and material purchase logs, which will be analysed in conjunction with primary survey data. The SPSS Statistics 22 software will be used for data analysis, a tool commonly used in construction research to analyse large datasets and perform regression analysis, reliability tests, and descriptive statistics. SPSS (Statistical Product and Service Solutions), originally developed by Norman Nie in 1968, is a powerful tool for analysing and evaluating project data, allowing construction managers to make informed decisions regarding resource allocation and waste management [3].

The findings of this research will contribute to understanding the factors driving material waste in construction and offer recommendations on how to minimise it. Effective waste management practices not only reduce environmental impact but also enhance the economic performance of construction projects, aligning with Sustainable Development Goal (SDG) 12, which advocates for sustainable consumption and production patterns. Thus, the research not only addresses practical issues in construction waste management but also contributes to broader sustainability objectives [4](Ajayi et al., 2017).

2. Construction Material Waste

Construction material waste refers to the unused, discarded, or surplus materials that are generated during construction activities. This waste can occur at various stages of construction, including planning, procurement, transportation, on-site storage, handling, and disposal. Construction waste includes materials that are surplus due to errors in measurement, waste during the transportation process, or damage during storage. These materials, which cannot be directly reused on-site, are typically sent to landfills or recycling facilities. According to several studies, construction waste has a significant environmental footprint, contributing to pollution, resource depletion, and increased costs for disposal.

Construction waste can be broadly classified into natural waste, direct waste, and indirect waste, each type of waste having its own causes and consequences for construction projects. Understanding these categories helps in devising effective strategies for waste minimisation and recycling.

2.1 Natural Waste

Natural waste refers to materials that are unavoidable by-products of the construction process. For instance, wood trimmings from cutting, excess paint left on cans, or dust generated during sanding are examples of natural waste. Although this type of waste is inherent to the construction process, it is important to control it to avoid it turning into direct waste. As noted by Poon (2001), while natural waste may not always be preventable, controlling its quantity within tolerable limits is essential to maintaining project efficiency and reducing environmental harm [5].

2.2 Direct Waste

Direct waste is generated through the actual construction process and often results from human error, poor planning, or suboptimal material handling. Examples include:

1. Transport and Delivery Waste
   This type of waste occurs when materials are damaged during delivery or unloading at the site. For instance, tiles may be cracked or cement may spill due to improper handling during transport [6].
2. Site Storage Waste
   Waste arises when materials are stored improperly on-site, leading to deterioration or contamination. For example, cement that absorbs moisture or steel that rusts due to poor storage conditions [4].
3. Conversion Waste
   This occurs when materials are cut, shaped, or altered into sizes that are not economically viable, such as leftover steel rebar, tiles, or timber after cutting.
4. Fixing Waste
   Waste produced during the installation of materials, including cement or bricks that are damaged during handling or application on-site.
5. Cutting Waste

Waste generated from cutting materials, such as excess concrete, rebar, or tiles, that are too small to be reused [7].

6. Application and Residue Waste
   Materials that spill or are left behind after application, such as hardened mortar or spilled paint, which cannot be reused in the project [8].
7. Criminal Waste
   Waste caused by theft or vandalism, which can occur if construction sites are not properly secured [5].

2.3 Indirect Waste

Indirect waste results from inefficiencies or decisions that occur outside the direct construction process. Examples include:

1. Substitution Waste
   Waste that occurs when a material is substituted with another material without proper planning, leading to excess material orders or unsuitable replacements.

2. Production Waste
   This includes surplus material used due to inefficiencies in the construction process, such as when workers use too much mortar because the walls are not built to the correct dimensions.

3. Negligence Waste
   Waste caused by human error or negligence on-site, such as excavation errors or using more material than necessary for a particular job [3].

2.4 Factors Contributing to Material Waste

Material waste during construction is driven by various factors, as outlined by [9], including:

1. Human Factors
   Lack of training, experience, or skill, leading to errors in material use and handling. Poor supervision also contributes to waste generation.
2. Management Issues
   Poor planning, weak project management, and ineffective communication among stakeholders lead to inefficient resource use and unnecessary waste generation.
3. Design and Documentation Problems
   Inconsistent or unclear design specifications, incomplete drawings, and frequent design changes all contribute to material waste. Poor documentation management can lead to confusion and mistakes on-site [10].
4. Material Issues
   Low-quality materials, improper ordering, and poor storage practices contribute significantly to material waste. Additionally, over-ordering due to inaccurate estimates results in surplus materials.
5. Execution Factors
   Inefficient construction methods, poor site layout, or inappropriate equipment can result in increased waste. Use of outdated or unsuitable tools and machinery can exacerbate this issue.
6. External Factors
   Environmental factors, such as adverse weather, or external damage caused by third parties, can also result in additional waste [11].

2.5 Strategies for Waste Prevention

Effective management of construction material waste is crucial to reducing its environmental and economic impact. Some key strategies include:

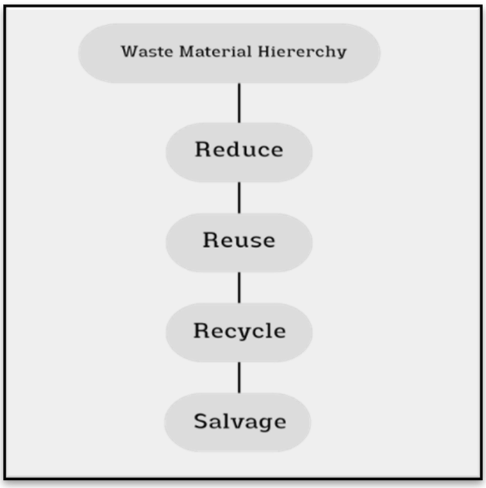

Fig. 1 *Hierarchy waste material*

1. Reduce
   Reduction refers to minimising the generation of material waste during the construction process. This can be achieved through careful planning, accurate material estimation, and efficient handling of materials on-site.
2. Reuse
   Reuse involves utilising construction materials in their original form at the project site. For example, leftover concrete or bricks can be reused in minor construction tasks without undergoing any processing.
3. Recycle
   Recycling is the process of transforming construction waste into new, valuable products. For instance, debris from demolished concrete can be crushed and repurposed as aggregate for new construction, reducing the need for virgin materials.
4. Salvage
   Salvaging involves transporting waste or surplus construction materials from the project site to be disposed of at designated landfills, sold, or handed over to third parties for reuse or recycling. This step ensures that the materials are managed sustainably and do not contribute to environmental pollution [12].

2.6 Waste Level Calculation

Waste level is a key metric for determining how much material is wasted relative to the total material requirements for a project. The waste level is calculated using the following formula:

$$Waste\ Level = \frac{Volume\ of\ Waste}{Volume\ of\ Required\ Materials} \quad (1)$$

This calculation helps quantify waste generation and assess the effectiveness of waste reduction strategies [5].

3. Research Methodology

Quantitative research is a systematic, planned, and structured type of research. This method is used to test hypotheses on a specific population or sample. Sampling is conducted randomly, data collection is carried out using research instruments, and data analysis involves quantitative or statistical methods aimed at testing predetermined hypotheses [13]–[15].

The primary issues examined and the goals to be achieved form the core of this research. The subject of this study is the construction project of a 4-storey office building. A quantitative approach was utilised to collect initial data through interviews with on-site employees and by distributing questionnaires to respondents. Based on the results of these interviews, data were processed using SPSS to determine the most significant factors contributing to material waste on-site.

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3.1 Population dan Sample

Sampling must be conducted in such a way as to obtain a sample that accurately represents the conditions of the population. The approach is based on the following formula:

$$n=N/(1+(Nx2D)) \quad (2)$$

Where:

n = Number of samples
N = Total population
D = Precision level

Using the eq. (2) , the sample size for this study can be calculated. Given a population size of 30 workers on the 4-storey office building project and a precision level of 10%, the calculation is as follows:

$$n=30/(1+(30x10\%x10\%)) = 29{,}12$$

Thus, the required sample size for this study is determined to be 30 respondents.

3.2 Data Collection Techniques

Data collection for this research involved both primary and secondary data sources.

1. Primary Data
   The primary data were collected through the distribution of questionnaires to on-site respondents. These questionnaires were designed to identify the factors contributing to material waste in the 4-storey office building project. Interviews with field workers were also conducted to gain deeper insights into specific issues causing material waste.
2. Secondary Data
   Secondary data were obtained from relevant organisations involved in the research, particularly PT XYZ, the contractor for the project. These data included text-based information such as:
   - BOQ (Bill of Quantities)
   - Daily construction reports
   - Material purchase summaries

3.3 Research Flow Chart

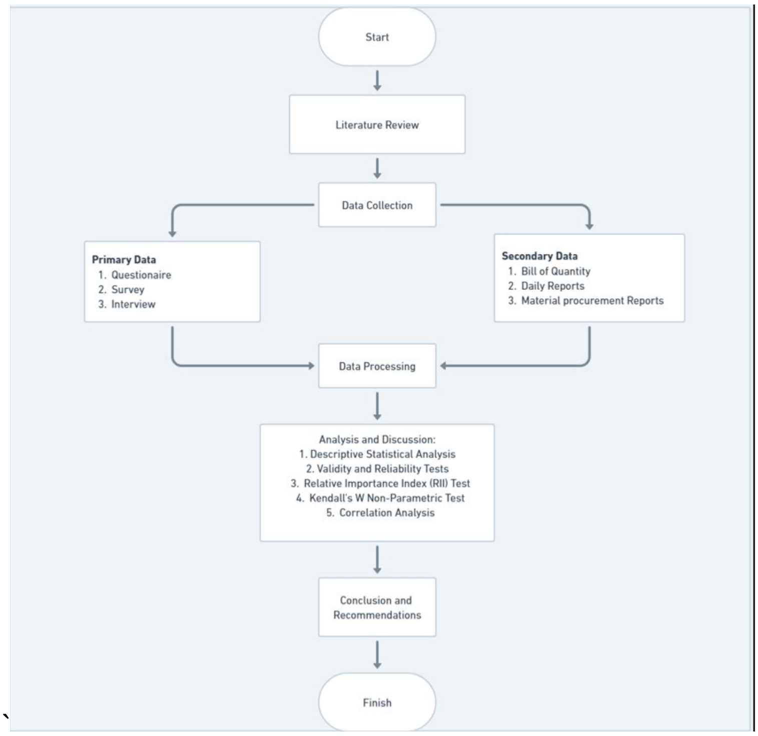

Fig. 2 *Research flowchart*

This flowchart outlines the process for conducting research and preparing a scientific journal article. Here's an explanation of the flow:

1. Start: The research process begins.
2. Literature Review: The researcher reviews existing studies and literature to understand the research gap and frame the study.
3. Data Collection:
   - Primary Data: Data is gathered using tools such as questionnaires, surveys, and interviews.
   - Secondary Data: Data is obtained from existing documents such as bills of quantity, daily reports, and material procurement reports.
4. Data Processing: The collected data is organised, cleaned, and prepared for analysis.
5. Analysis and Discussion:
   - Descriptive Statistical Analysis: Summarises the basic features of the data.
   - Validity and Reliability Tests: Ensures that the data collection instruments produce consistent and accurate results.
   - Relative Importance Index (RII) Test: Assesses the relative importance of variables or factors.
   - Kendall's W Non-Parametric Test: Measures agreement between different raters or rankings.
   - Correlation Analysis: Examines the relationships between different variables.
6. Conclusion and Recommendations: Based on the findings, the researcher draws conclusions and provides actionable recommendations.
7. Finish: The research process is completed, and the journal article is finalised.

This structured approach ensures a comprehensive and systematic workflow for conducting and presenting research.

4. Analysis and Discussion

4.1 Respondent Profile

1. Gender of Respondents

Gender is categorised into two variations: male and female. The percentage distribution of gender is calculated in Table 1 below.

Table 1 *Percentage of respondents by gender*

Gender	Number	Percentage (%)
Male	20	66,7
Female	10	33,3
Total	30	100

Based on Table 1, it is evident that there are 20 male respondents, representing 66.7%, and 10 female respondents, representing 33.3%.

2. Age of Respondents

The respondents' educational qualifications are categorised into four levels: Junior High School (SMP), Senior High School (SMA), Diploma (D3), and Bachelor's Degree (S1). Table 3 below outlines the percentage distribution.

Table 2 *Percentage of respondents by age*

Age	Number	Percentage(%)
20 – 30 Years	16	53,3
31 – 40 Years	7	23,3
41 – 50 Years	6	20
≥ 51 Years	1	4,4
Total	30	100

As shown in Table 2, the majority of respondents fall in the 20–30 years age range, representing 53.3% (16 respondents). This is followed by 31–40 years with 23.3% (7 respondents), 41–50 years with 20% (6 respondents), and ≥ 51 years with 4.4% (1 respondent).

3. Education of Respondents
The respondents' educational qualifications are categorised into four levels: Junior High School (SMP), Senior High School (SMA), Diploma (D3), and Bachelor's Degree (S1). Table 3 below outlines the percentage distribution.

Table 3 *Distribution of respondents by education level*

Education Level	Number	Percentage (%)
Secondary School	0	0
Sixth Form / College	4	13,3
Diploma	1	3,3
Bachelor's Degree	25	83,3
Master's Degree	0	0
Total	30	100

Based on Table 2, the majority of respondents hold a Bachelor's Degree, accounting for 83.3% (25 respondents), followed by Sixth Form/College with 13.3% (4 respondents), and Diploma with 3.3% (1 respondent). No respondents reported having qualifications from Secondary School or a Master's Degree.
4. Type of Organisation or Business Entity
The organisations or businesses represented by the respondents are categorised into four types: Contractor, Consultant, Subcontractor/Foreman, and Others. The distribution of respondents by organisation type is presented in Table 4 below.

Table 4 *Distribution of respondents by organisation type*

Organisation Type	Number	Percentage (%)
Contractor	16	53,3
Consultant	10	33,3
Subcontractor/Foreman	2	6,7
Others	2	6,7
Total	30	100

Based on Table 4, the majority of respondents work with contractors, accounting for 53.3% (16 respondents), followed by consultants with 33.3% (10 respondents), and Subcontractors/Foremen and Others, both at 6.7% (2 respondents each).

5. Work Experience of Respondents
Respondents' work experience is categorised into four levels: 1–5 years, 6–10 years, 11–20 years, and ≥ 21 years. Table 5 outlines the distribution.

Table 5 *Distribution of respondents by work experience*

Work Experience	Number	Percentage (%)
1 - 5 Years	7	23,3
6 - 10 Years	18	60
11 - 20 Years	4	13,3
≥ 21 Years	1	3,3
Total	30	100

As shown in Table 5, the majority of respondents have 6–10 years of work experience, accounting for 60% (18 respondents). This is followed by 1–5 years with 23.3% (7 respondents), 11–20 years with 13.3% (4 respondents), and ≥ 21 years with 3.3% (1 respondent).

4.2 Analysis of Material Waste Types

This section presents the results from the questionnaires completed by the respondents. After calculating the percentage of material waste quantities, the dominant waste materials can be identified. The following table shows the percentage of different material waste types in the 4-storey office building project.

Table 6 *Ranking of the most frequently selected material waste types by respondents*

No	Code	Material Waste Type	Response Weight Percentage	Rank
1	A10	Concrete	78.67%	**1**
2	A7	Bricks	70.67%	**2**
3	A6	Reinforcing Steel	70.00%	**3**
4	A11	Cement	69.33%	**4**
5	A4	Sand	68.00%	**5**
6	A5	Crushed Stone/Gravel	66.67%	**6**
7	A3	Wood Planks (construction board)	62.00%	**7**
8	A8	Formwork Wood	62.00%	**8**
9	A9	Plywood/Triplex	62.00%	**9**
10	A13	Bondek	60.00%	**10**
11	A2	Thread/String	58.67%	**11**
12	A1	Excavated Soil	56.67%	**12**
13	A12	Mortar/Plaster	56.67%	**13**

Based on Table 6, the most frequently occurring material waste type is concrete, with 78.67% of respondents selecting it. This is followed by bricks (70.67%), reinforcing steel (70%), cement (69.33%), sand (68%), crushed stone (66.67%), wood planks (62%), formwork wood (62%), plywood (62%), Bondek (60%), thread/string (58.67%), and excavated soil and mortar (56.67%).

4.3 Analysis of Factors Causing Material Waste

Based on the 1-5 scale ratings from the questionnaire, the factors most frequently selected by respondents as contributing to material waste in the 4-storey office building project are shown in Table 7.

Table 7 *Ranking of factors contributing to material waste frequently selected by respondents*

Code	Response Weight (%)	Rank	Code	Response Weight (%)	Rank
B3	80.00%	1	B9	66.67%	24
B2	76.67%	2	C5	66.67%	25
B4	74.00%	3	F1	66.67%	26
B6	72.00%	4	G3	66.67%	27
A2	71.33%	5	H3	66.67%	28
B8	70.00%	6	B7	66.00%	29
E1	70.00%	7	B10	66.00%	30
B5	69.33%	8	A1	65.33%	31
D2	69.33%	9	C3	65.33%	32
G1	69.33%	10	E4	65.33%	33
G2	69.33%	11	E6	65.33%	34
B1	68.67%	12	F2	65.33%	35
B11	68.67%	13	H4	65.33%	36
E5	68.67%	14	H5	65.33%	37
B12	68.00%	15	E3	64.67%	38
D1	68.00%	16	I1	64.67%	39

E2	68.00%	17	H1	64.00%	40
H2	68.00%	18	C1	63.33%	41
H6	68.00%	19	C4	63.33%	42
C2	67.33%	20	D3	63.33%	43
H7	67.33%	21	J1	62.67%	44
I3	67.33%	22	I2	62.00%	45
J2	67.33%	23			

As shown in Table 7, the most frequently selected factor contributing to material waste is B3, with 80% of respondents choosing it. This is followed by B2 (76.67%), B4 (74%), and B6 (72%).

The validity test results for the material waste factors are provided using SPSS 22. Table 8. shows the calculated correlation values (R Calculated) compared to the critical value (R Table) at a significance level of 0.361. If the R Calculated is higher than the R Table value, the factor is considered valid.

Table 8 *Recapitulation of validity test results*

No.	Category	Code	R Calculated	R Table (N-2)	Remarks
1	Contract	A1	0.798	0.361	Valid
2		A2	0.786	0.361	Valid
3	Design	B1	0.517	0.361	Valid
4		B5	0.376	0.361	Valid
5		B6	0.454	0.361	Valid
6		B7	0.392	0.361	Valid
7		B8	0.383	0.361	Valid
8		B9	0.746	0.361	Valid
9		B10	0.51	0.361	Valid
10		B12	0.491	0.361	Valid
11	Procurement	C1	0.481	0.361	Valid
12		C2	0.617	0.361	Valid
13		C3	0.642	0.361	Valid
14		C4	0.721	0.361	Valid
15		C5	0.478	0.361	Valid
16	Storage	D1	0.623	0.361	Valid
17		D2	0.747	0.361	Valid
18		D3	0.439	0.361	Valid
19	Handling	E1	0.664	0.361	Valid
20		E2	0.382	0.361	Valid
21		E3	0.606	0.361	Valid
22		E4	0.366	0.361	Valid
23		E5	0.635	0.361	Valid
24		E6	0.509	0.361	Valid
25	Facility	F1	0.6	0.361	Valid
26		F2	0.691	0.361	Valid
27	Management & Planning	G1	0.628	0.361	Valid
28		G2	0.625	0.361	Valid
29		G3	0.647	0.361	Valid
30	Operation	H1	0.38	0.361	Valid
31		H2	0.583	0.361	Valid
32		H3	0.553	0.361	Valid

No.	Category	Code	R Calculated	R Table (N-2)	Remarks
33		H4	0.624	0.361	Valid
34		H6	0.383	0.361	Valid
35		H7	0.521	0.361	Valid
36	Workers	I1	0.634	0.361	Valid
37		I2	0.655	0.361	Valid
38		I3	0.752	0.361	Valid
39	Others	J1	0.827	0.361	Valid
40		J2	0.794	0.361	Valid

From Table 8, the material waste types that passed the validity test using SPSS 22 are as follows: The contract category (A1) has a correlation of 0.798, which is greater than the critical value of 0.361, and is therefore considered valid. The same applies to other variables that have a calculated correlation value higher than the table value of 0.361. The statements from the questionnaire items that did not pass the validity test are presented as a reference for the material waste questionnaire, as shown in Table 9 below.

Table 9 *Recapitulation of invalid results in the validity test*

No	Category	Code	R Calculated	R Critical (N-2)	Remark
1	Design	B2	0.276	0.361	Tidak Valid
2		B3	0.286	0.361	Tidak Valid
3		B4	0.321	0.361	Tidak Valid
4		B11	0.218	0.361	Tidak Valid
5	Operation	H5	0.304	0.361	Tidak Valid

From Table 4.11, the material waste types that did not pass the validity test using SPSS 22 are as follows: B2 (design category) has a correlation of 0.276, which is lower than the critical value of 0.361, and therefore, variable B2 (design category) is considered invalid. The same applies to other variables that have a calculated correlation value lower than the table value of 0.361. Out of the 45 validity test statements, 40 statements were found to be valid. This ensures that the questionnaire tool for assessing the factors contributing to material waste is reliable and consistent when re-measured. A reliability test was conducted using SPSS 22. The following are the results from the reliability test output for each category of factors contributing to material waste. A variable is considered reliable if its Cronbach's alpha value is greater than 0.60. If it is lower, the variable is considered unreliable.

Table 10 *Recapitulation of reliability test results*

Variable	Kode	Cronbach' Alpha	N of Items	Hasil
Contract	A	0,826	3	Reliable
Design	B	0,711	9	Reliable
Procurement	C	0,728	6	Reliable
Storage	D	0,703	4	Reliable
Handling	E	0,697	7	Reliable
Facilities	F	0,677	3	Reliable
Management and Planning	G	0,721	4	Reliable
Operation	H	0,705	7	Reliable
Workers	I	0,758	4	Reliable
Others	J	0,840	3	Reliable

Based on the questionnaire results, the factors contributing to material waste that passed the Validity Test and Reliability Test can be detailed according to the number of respondents who selected a score between 1 and 5 for each statement used as the questionnaire tool. The data from the questionnaire regarding the factors contributing to material waste, which have been ranked and categorised, are presented below.

Table 11 *Recapitulation of relative importance index (RII) test results*

Code	RII	Rank	Importance Level	Code	RII	Rank	Importance Level
H6	0,707	1	High	E6	0,653	24	High
B2	0,693	2	High	G3	0,653	25	High
B3	0,693	3	High	H4	0,653	26	High
D2	0,693	4	High	B6	0,647	27	High
E1	0,687	5	High	B10	0,647	28	High
H7	0,687	6	High	E3	0,647	29	High
I3	0,687	7	High	E4	0,647	30	High
G1	0,68	8	High	H2	0,647	31	High
B4	0,673	9	High	H5	0,647	32	High
E5	0,673	10	High	B9	0,64	33	High
C2	0,667	11	High	H1	0,64	34	High
C5	0,667	12	High	I1	0,64	35	High
D1	0,667	13	High	A1	0,633	36	High
E2	0,667	14	High	D3	0,633	37	High
B1	0,66	15	High	F2	0,633	38	High
B12	0,66	16	High	C3	0,627	39	High
F1	0,66	17	High	C4	0,627	40	High
G2	0,66	18	High	J1	0,627	41	High
H3	0,66	19	High	J2	0,627	42	High
B5	0,653	20	High	A2	0,62	43	High
B7	0,653	21	High	I2	0,62	44	High
B8	0,653	22	High	C1	0,613	45	High
B11	0,653	23	High				

4.4 Analysis of Material Waste Prevention Efforts

Data collection for this study was conducted by distributing questionnaires to 30 respondents involved in the construction of the 4-storey office building. The questionnaire statements used in this study were divided into different categories. The prevention efforts for material waste consist of four categories: Recycle, Reuse, Reduce, and Salvage. The results of the questionnaire on material waste prevention efforts are as follows:

Table 12 *Ranking of the most frequently selected material waste prevention efforts by respondents*

Code	Response Weight (%)	Rank
D3	80.00%	1
A21	78.67%	2
C1	78.00%	3
B2	76.00%	4
C3	75.33%	5
C2	74.67%	6
A7	73.33%	7
D1	73.33%	8
D4	73.33%	9
A16	72.67%	10
A17	72.67%	11
A13	72.00%	12
A1	71.33%	13
A3	71.33%	14
A8	71.33%	15

Code	Response Weight (%)	Rank
A6	70.67%	16
A14	70.67%	17
A20	70.67%	18
B1	70.67%	19
A2	70.00%	20
A5	69.33%	21
A12	69.33%	22
A18	69.33%	23
A9	68.67%	24
A10	68.67%	25
A19	68.67%	26
A4	68.00%	27
A11	67.33%	28
A15	67.33%	29
D2	63.33%	30

Based on Table 12, the most frequently chosen material waste prevention efforts include D3 (80%), A21 (78.67%), and C1 (78%).

In this validity test study, the results from 30 questionnaires were analysed with a 5% significance level using SPSS 22 software. The following table shows the validity test results for material waste prevention efforts in each category.

Table 13 *Recapitulation of validity test results*

Category	Code	R Calculated	R Table (N-2)	Remarks	Category	Code	R Calculated	R Table (N-2)	Remarks
Recycle	A1	0,406	0,361	Valid	Recycle	A18	0,653	0,361	Valid
	A2	0,372	0,361	Valid		A19	0,506	0,361	Valid
	A3	0,48	0,361	Valid		A21	0,375	0,361	Valid
	A5	0,451	0,361	Valid	Reuse	B1	0,798	0,361	Valid
	A6	0,407	0,361	Valid		B2	0,842	0,361	Valid
	A7	0,699	0,361	Valid	Recycle	C1	0,796	0,361	Valid
	A8	0,488	0,361	Valid		C2	0,813	0,361	Valid
	A9	0,535	0,361	Valid		C3	0,741	0,361	Valid
	A12	0,663	0,361	Valid	Salvage	D1	0,6	0,361	Valid
	A13	0,382	0,361	Valid		D2	0,638	0,361	Valid
	A15	0,441	0,361	Valid		D3	0,754	0,361	Valid
	A16	0,459	0,361	Valid		D4	0,393	0,361	Valid
	A17	0,529	0,361	Valid					

From Table 13, the material waste prevention variables that passed the validity test using SPSS 22 are listed. For instance, A1 (Recycle category) has a calculated correlation value of 0.406, which is greater than the table value of 0.361, thus making the variable valid. Similarly, other variables with correlation values in the table value of 0.361 are also considered valid.

Next, the statements from the questionnaire that did not pass the validity test was shown in Table 14 below.

Tabel 14 *Recapitulation of invalid validity test results*

No	Category	Code	R Calculated	R Table (N-2)	Remarks
1	*Recycle*	A4	0,3	0,361	Tidak Valid
2		A10	0,359	0,361	Tidak Valid
3		A11	0,334	0,361	Tidak Valid
4		A14	0,139	0,361	Tidak Valid

5	A20	0,346	0,361	Tidak Valid

In Table 14, the material waste prevention items that did not pass the validity test using SPSS 22 are shown. For example, A10 (Recycle category) has a calculated correlation value of 0.359, which is lower than the table value of 0.361, and therefore, A10 is considered invalid.

Out of the 30 validity test statements, 25 statements were valid. To ensure the reliability and consistency of the questionnaire tool for material waste prevention, a reliability test was conducted using SPSS 22 software. The following are the reliability test results for each category of material waste prevention.

Table 15 *Recapitulation of reliability test results*

Variable	Code	Cronbach's Alpha	Number of Items	Result
Reduce	A	0,825	18	Reliable
Reuse	B	0,707	5	Reliable
Recycle	C	0,854	3	Reliable
Salvage	D	0,86	4	Reliable

4.5 Discussion of Material Waste Type

Based on the analysis, the most common types of construction material waste were identified, as seen in Table 6. The three most dominant types of waste material are outlined in Table 16.

Table 16 *Discussion of waste level for material types*

No	Material Type	Unit	BoQ Volume	% Purchased	Logistics Volume	Installed Volume	Waste Volume	Waste Level (%)
1	Concrete	m^3	485.80	92.48	449.26	441.54	7.72	5.211
2	Bricks	m^2	1253.74	91.72	1149.90	1099.23	50.67	4.406
3	Reinforcing Steel	kg	46216.84	91.61	42320.45	41849.61	470.84	3.447

4.6 Discussion of Factors Causing Material Waste

The factors that contribute to material waste affect the efficiency of material use. In this study, three main factors that frequently cause material waste have been identified, as shown in Table 17.

Table 17 *Discussion of waste level for material waste causes*

No	Code	Cause of Waste
1	H6	Inaccurate measurement on-site leading to excess volume
2	B2	Design changes and complex design details
3	B3	Errors in design during construction

From Table 17, the dominant types of material waste and their causes on-site can be explained as follows:

1. Inaccurate measurement on-site leading to excess volume
   Human error can be a primary cause of inaccurate measurements. Mistakes in using measuring tools, reading scales, or recording results can lead to discrepancies.
2. Design changes and complex design details
   Projects with many components or systems that need to be integrated can result in design changes due to the complexity of fitting or connecting these elements.
3. Errors in design during construction
   Lack of clarity or insufficient communication between design and construction teams can lead to misunderstandings. Ambiguous or poorly communicated information can trigger errors during the implementation of the design on-site.

4.7 Discussion of Material Waste Prevention Efforts

Efforts that need to be taken by the project team to address material waste involve prevention and minimisation strategies. The top three prevention efforts, as ranked in Table 18, are as follows:

Table 18. *Discussion of waste level for material waste prevention efforts*

No	Variable Code	Prevention Efforts
1	A3	Improving the accuracy of estimates and orders.
2	A11	Recording materials that can be reused, recycled, or classified as waste.
3	B1	Utilising materials for alternative functions.

4.8 Relationship Between Prevention Efforts and Causes of Material Waste

To minimise material waste during construction, effective construction waste management should focus on utilising the remaining materials. This can be achieved through the waste hierarchy concept, which involves applying Recycle, Reuse, Reduce, and Salvage strategies, as detailed below.

Table 19 *Discussion of waste level for material waste types and prevention efforts*

No.	Material Type	Cause of Waste	Prevention Effort
1	Concrete	Inaccurate measurement on-site leading to excess volume	Improving accuracy in estimates and ordering.
		Design changes and complex design details	Recording materials that can be reused, recycled, or are waste.
		Errors in design during construction	Utilising materials for alternative functions.
2	Bricks	Inaccurate measurement on-site leading to excess volume	Improving accuracy in estimates and ordering.
		Design changes and complex design details	Recording materials that can be reused, recycled, or are waste.
		Errors in design during construction	Utilising materials for alternative functions.
3	Reinforcing Steel	Inaccurate measurement on-site leading to excess volume	Improving accuracy in estimates and ordering.
		Design changes and complex design details	Recording materials that can be reused, recycled, or are waste.
		Errors in design during construction	Utilising materials for alternative functions.

Table 19 shows the correlation between the analysed types of material waste, their causes, and the prevention efforts for material waste on-site.

5. Conclusion

This study aimed to analyse material waste in the construction of a 4-storey office building, with a focus on identifying the types of waste, their causes, and effective prevention strategies. Based on the findings, the following conclusions can be drawn:

1. Prevalent Material Waste Types:
   Concrete accounted for the highest material waste at 5.211%, followed by Bricks (4.406%) and Reinforcing Steel (3.477%). These materials were identified as the most significant contributors to waste in the construction process.
2. Key Causes of Material Waste:
   Inaccurate on-site measurements, leading to overestimation of material volumes, was the leading cause of waste.
   Design changes and the complexity of design details also contributed significantly to material waste during construction.
   Errors in design during the construction phase further exacerbated waste generation.

3. Recommended Prevention Strategies:
   To minimise waste, it is essential to improve the accuracy of material estimates and ordering processes. This can reduce over-ordering and excess material.
   Effective tracking and recording of materials that can be reused, recycled, or repurposed is crucial for minimising waste.
   Additionally, repurposing leftover materials for alternative functions should be incorporated into construction practices to reduce waste and make use of surplus materials.

The findings of this study highlight the critical importance of accurate planning, precise measurements, and effective material management in reducing waste and improving the efficiency of construction projects. By implementing these strategies, construction projects can significantly reduce material waste, leading to both economic benefits and environmental sustainability. Finally, future research could explore the impact of advanced technologies such as AI and machine learning for predictive waste management, as well as evaluate the long-term financial and environmental benefits of these prevention strategies in large-scale construction projects.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

All authors equally contributed to this manuscript.

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