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Analysis of Construction Material Waste in Hospital Building Projects Using Pareto and Fishbone Approaches

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ABSTRACT

Material is one of the most important components in construction projects because it serves as the primary element of building structures and significantly influences project costs. Ineffective material management can result in construction material waste, leading to increased costs and reduced resource efficiency. This study aims to identify the dominant waste-generating materials and analyze the factors causing material waste in the Hermana Lembean General Hospital construction project. Data were collected from as-built drawings, material logistics reports, and field interviews. The Pareto method was used to determine the dominant waste materials, while the Fishbone Diagram method was applied to identify the root causes of material waste. The results showed that the total construction material waste generated during the project was 3,951.784 units. Pareto analysis indicated that reinforcing steel (53.21%), wall ceramic 60 × 60 cm (11.38%), lightweight brick (8.49%), and floor ceramic 60 × 60 cm (7.49%) were the dominant waste materials, accounting for more than 80% of the total waste volume. Fishbone Diagram analysis revealed that material waste was mainly caused by machine, method, material, manpower, and measurement factors. These findings can be used to improve material management and reduce waste in future construction projects.

INTRODUCTION

Infrastructure development has continued to increase in recent years, both by the government and the private sector, to support economic growth and meet the increasing needs of society (Situmorang, 2023; Nugroho et al., 2025). Various construction projects, including roads, bridges, office buildings, residential buildings, hospitals, and other public facilities, are continuously developed to improve community welfare and economic activities. In construction projects, materials are among the most critical resources because they constitute the primary components of building structures and significantly influence overall project costs. Previous studies have reported that material costs may account for approximately 40–60% of total construction project expenditures, highlighting the importance of effective material management in achieving project efficiency (Fitriani, 2022; Gultom & Sutandi, 2023).

In practice, ineffective material management may result in construction material waste. Construction material waste refers to materials that are purchased or prepared for construction activities but are not ultimately incorporated into the completed structure (Susanti & S, 2021; Al-Btoosh et al., 2023). Material waste can arise from various causes, including inaccurate material planning, improper storage systems, transportation damage, errors in cutting and installation processes, poor handling practices, and inadequate supervision during project execution (Gultom & Sutandi, 2023; Mokosuli et al., 2023; Hussien, 2021). These conditions can increase project costs, reduce productivity, and negatively affect resource utilization efficiency. Furthermore, construction waste may generate environmental impacts through increased disposal requirements and inefficient consumption of natural resources (Tafesse et al., 2022; Sagan & Mach, 2025).

Several previous studies have examined construction material waste and its impact on project performance. Mokosuli et al. (2023) applied Pareto Analysis and Fishbone Diagram methods to identify dominant waste materials and determine the factors causing waste in residential construction projects. Similarly, Permana Putra et al. (2024) found that a relatively small number of material types contributed to most of the waste volume generated during construction activities. Yuliana et al. (2024) reported that material waste commonly occurs in reinforcing steel, masonry materials, and finishing materials due to planning inaccuracies and implementation errors. In addition, Aisyah et al. (2023) emphasized the importance of waste management and lean construction principles to improve project efficiency and reduce non-value-added activities associated with material losses. These studies demonstrate that identifying dominant waste materials and their causes is essential for improving construction management performance.

Despite these contributions, several limitations remain in the existing literature. Most previous studies focused on residential buildings, housing developments, or general building projects (Mokosuli et al., 2023; Permana Putra et al., 2024). Furthermore, the characteristics of construction waste vary according to project type, construction methods, material specifications, management practices, and site conditions (Al-Btoosh et al., 2023; Ramadhan et al., 2025). Consequently, the findings of previous studies cannot be directly generalized to hospital construction projects, which involve more complex functional requirements, stricter quality standards, and intensive utilization of consumable materials. Although construction waste has been widely investigated, studies specifically addressing material waste in hospital construction projects remain limited, particularly within the Indonesian construction industry. This condition indicates the existence of a research gap regarding the identification of dominant waste-generating materials and the analysis of waste-causing factors in hospital construction projects. Therefore, further investigation is required to provide empirical evidence regarding construction material waste characteristics within healthcare facility development projects.

The novelty of this study lies in the integrated application of Pareto Analysis and Fishbone Diagram methods to evaluate construction material waste in the Hermana Lembean General Hospital construction project. Unlike previous studies that mainly focused on residential or commercial buildings, this research investigates a hospital construction project and combines quantitative waste identification with systematic root-cause analysis. This approach enables a more comprehensive understanding of both dominant waste materials and the factors contributing to their occurrence.

Therefore, this study aims to identify the dominant construction materials generating waste in the Hermana Lembean General Hospital construction project using Pareto Analysis and to analyze the factors causing waste using the Fishbone Diagram method. The findings are expected to contribute to the development of construction waste management knowledge and provide practical recommendations for improving material planning, procurement, storage, handling, and utilization. Furthermore, the results may assist contractors and project managers in reducing material waste, improving resource efficiency, supporting sustainable construction practices, and controlling project costs in future construction projects.

RESEARCH METHODS

This study was conducted at the Hermana Lembean General Hospital construction project located on Jl. A. Mononutu, Lembean Village, Kauditan District, North Minahasa Regency, Indonesia. The project was selected as the research object because it involved intensive use of consumable construction materials and had the potential to generate material waste during the construction process. The study focused on identifying dominant waste materials and analyzing the factors contributing to their occurrence. The research employed a descriptive quantitative approach supported by qualitative analysis. Quantitative analysis was used to determine the volume of construction material waste and identify dominant waste materials through Pareto Analysis. Qualitative analysis was conducted using the Fishbone Diagram method to determine the root causes of waste generation.

The study began with a literature review to obtain theoretical foundations related to construction material management, construction waste, Pareto Analysis, and Fishbone Diagram applications in construction projects. The literature sources included scientific journals, conference proceedings, books, and previous studies relevant to construction waste management.

The data used in this study consisted of primary and secondary data. Primary data were collected through interviews and brainstorming sessions with project personnel directly involved in construction activities. The respondents consisted of twenty individuals selected using purposive sampling. This sampling technique was chosen because the respondents possessed direct knowledge and experience regarding material procurement, storage, handling, and utilization during project execution. The respondents included one Project Manager, one Site Manager, one Logistics Officer, one Quality Control Engineer, two Site Engineers, four Supervisors, and ten construction workers. Their work experience ranged from three to more than ten years in construction projects. The number of respondents was considered sufficient because information obtained from interviews had reached saturation, where no significant new factors related to material waste were identified.

Secondary data were obtained from project documentation, including as-built drawings, daily reports, weekly reports, material logistics records, and material price data. The as-built drawings were used to calculate the installed material volume, while logistics records were used to determine the quantity of purchased and available materials during project implementation. Material price data were utilized to support the evaluation of waste-related costs.

To ensure data reliability, the installed material volumes calculated from the as-built drawings were cross-checked with project progress reports and verified through discussions with project engineers. Similarly, purchased material quantities obtained from logistics reports were compared with procurement records and warehouse inventory reports. Any discrepancies identified during the verification process were clarified with the project management team before the data were used for analysis. The analysis procedure consisted of several stages. First, the installed material volume was calculated based on the as-built drawings. Second, the volume of purchased or ready-to-use materials was determined from logistics records. Third, the volume of material waste was calculated as the difference between the purchased material volume and the installed material volume using Equation (1).

$$Waste\ Material\ Volume = \text{Purchased Material Volume} - \text{Installed Material Volume} \tag{1}$$

A positive value indicated unused material remaining in storage or on-site, whereas a negative value indicated that the installed material volume exceeded the initial estimated quantity due to technical adjustments during construction. After determining the waste volume of each material, Pareto Analysis was conducted to identify the dominant materials contributing to construction waste. The percentage contribution of each material was calculated using Equation (2).

$$Percent\ (\%) = \frac{Waste\ Material\ Volume}{Total\ Waste\ Material} \ \text{x}\ 100\% \tag{2}$$

The cumulative percentage was then calculated using Equation (3).

$$Cummulative\ Percentage\ (\%) = \Sigma\ \text{Percentage Contribution} \tag{3}$$

The materials were arranged in descending order according to their waste volume contribution and presented in a Pareto Diagram. Based on the Pareto principle (80/20 rule), materials contributing to approximately 80% of the cumulative waste volume were classified as dominant waste materials and selected for further analysis. Following the Pareto Analysis, the Fishbone Diagram method was applied to identify the root causes of dominant material waste. The preparation of the Fishbone Diagram was conducted through three stages. First, potential causes of waste were identified from interview results and field observations. Second, brainstorming sessions were conducted with project personnel to classify and discuss the identified causes. Third, the causes were grouped into five categories: Manpower, Method, Material, Machine, and Measurement.

The resulting Fishbone Diagram was subsequently reviewed and validated by experienced project personnel, including the Project Manager, Site Manager, and Site Engineers, to ensure that the identified causal factors accurately reflected actual project conditions. Factors that received consistent agreement during the validation process were retained as the final causes of material waste. The overall research procedure consisted of literature review, data collection, verification of project documents, calculation of installed and purchased material volumes, determination of waste material volumes, Pareto Analysis, Fishbone Diagram Analysis, validation of findings, and formulation of recommendations for improving construction material management. The complete research process is illustrated in the research flowchart presented in Figure 1.

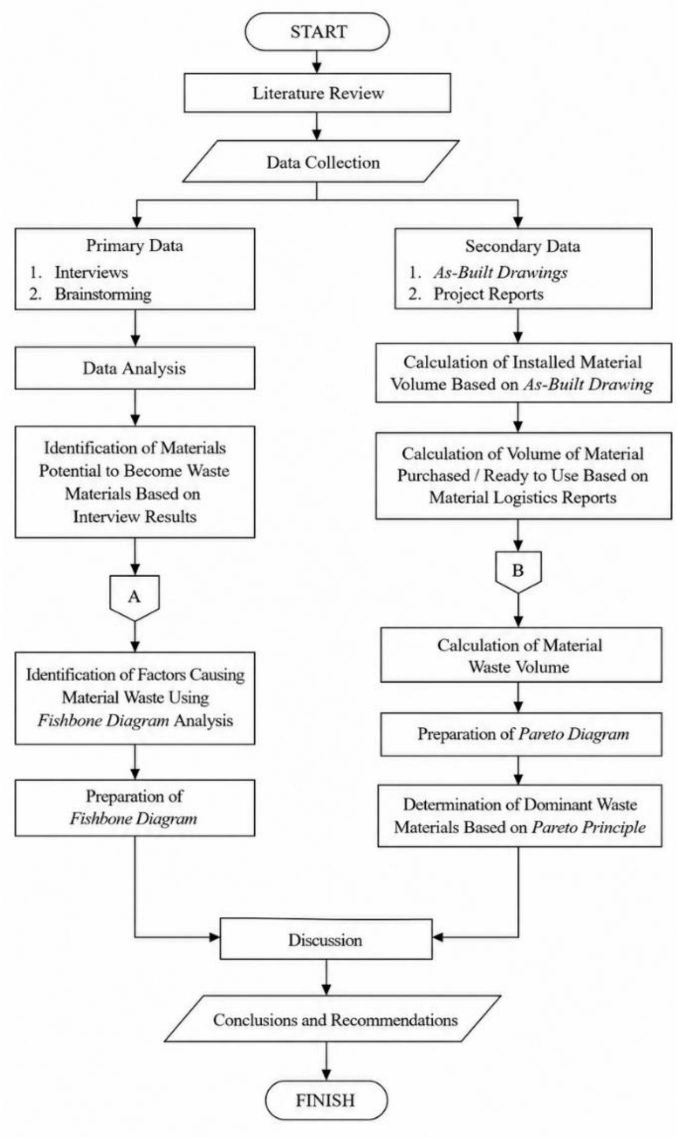


Figure 1. Flowchart

RESULTS AND DISCUSSION

General Project Information

The object of this research was the Hermana Lembean General Hospital construction project located on Jl. A. Mononutu, Lembean Village, Kauditan District, North Minahasa Regency. The project was carried out by PT. Cakra Buana Megah with a contract value of IDR 7,703,899,500 under a lump sum fixed-price contract system. The construction project had a building area of 882.7 m² and was completed within 127 calendar days starting from August 18, 2025. The project was supervised by Ar. Sr. Anas Sambine, SJMJ, together with the supervisory team from Hermana Lembean General Hospital.

This project was selected as the research object because construction activities during implementation had the potential to generate material waste, particularly consumable materials. Therefore, the project was considered suitable for analyzing the occurrence of construction material waste and identifying the factors causing waste generation during construction activities.

Material Waste Volume Calculation

The volume of material waste was obtained from the difference between the total volume of ready-to-use materials and the volume of materials installed in the field. The calculation results are presented in Table 1.

Table 1. Material Waste Volume Calculation

No	Material	Unit	Material Volume		
			Ready-to-use Material Volume	Installed Material Volume	Waste Material Volume
1	Sand	m³	355.67	316.332	39.343
2	Crushed Stone / Split 2/3	m³	111.623	105.179	6.444
3	River Stone / Broken Stone	m³	244.368	238.921	5.447
4	Lightweight Brick	pcs	12,505.000	12,169.658	335.343
5	Reinforcing Steel	kg	16,132.180	14,029.283	2,102.897
6	Floor Ceramic 60 × 60	pcs	2,832.319	2,536.199	296.120
7	Wall Ceramic 60 × 60	pcs	1,855.650	1,405.936	449.714
8	Plinth Ceramic 10 × 60	pcs	1,174.600	882.683	291.918
9	Galvanized Hollow Section	m	4,545.320	4,302.906	242.414
10	Screw Nails	kg	124.996	118.330	6.666
11	Gypsum 9 mm	sheet	290.548	273.562	16.987
12	GRC / Equivalent Thickness 4 mm	sheet	142.057	136.202	5.855
13	Primer Paint	kg	479.020	442.749	36.271
14	Finish Paint	kg	1,095.455	1,009.151	86.305
15	Lightweight Steel Roof Frame ex Prima Truss / Equivalent C75-0.75	bar	1,271.485	1,302.147	-30.661
16	Silver Spandek Roof ex Prima Deck Thickness 0.35	m²	1,324.050	1,355.979	-31.929
17	Bubble Foil Insulation Thickness 4 mm	m²	1,456.455	1,491.577	-35.122

18	Aluminum Ridge Flashing Thickness 0.35	m	153.200	185.847	-32.647
19	Kalsiboard Fascia Board t = 30 cm	m	212.500	182.440	30.060
	Total Positive Waste Material Volume				**3,951.784**

In the table above, positive waste values indicate that the materials were not fully installed and remained unused at the project site or storage area. Meanwhile, negative waste values indicate that the installed material volume exceeded the initial estimation due to technical adjustments and field conditions during the construction process.

Identification of Dominant Material Waste

To identify the most dominant types of material waste in this project, the Pareto method was applied. This method is based on the principle known as Pareto's Law 80/20, which states that a small number of factors generally contribute to the majority of problems. In this study, the calculation results of material waste volume were arranged from the largest to the smallest value.

The cumulative percentage of each material was subsequently determined to identify the dominant materials contributing to the total waste volume. The results of the analysis used to prepare the Pareto Diagram are presented in Table 2.

Table 2. Pareto Analysis of Construction Material Waste Contribution

No	Material	Waste Material Volume	Percent (%)	Cummulative Percent (%)
1	Reinforcing Steel	2,102.897	53.21%	53.21%
2	Wall Ceramic 60 × 60	449.714	11.38%	64.59%
3	Lightweight Brick	335.343	8.49%	73.08%
4	Floor Ceramic 60 × 60	296.120	7.49%	80.57%
5	Plinth Ceramic 10 × 60	291.918	7.39%	87.96%
6	Galvanized Hollow Section	242.414	6.13%	94.09%
7	Finish Paint	86.305	2.18%	96.28%
8	Sand	39.343	1.00%	97.27%
9	Primer Paint	36.271	0.92%	98.19%
10	Kalsiboard Fascia Board t = 30 cm	30.060	0.76%	98.95%
11	Gypsum 9 mm	16.987	0.43%	99.38%
12	Screw Nails	6.666	0.17%	99.55%
13	Crushed Stone / Split 2/3	6.444	0.16%	0.16%
14	GRC / Equivalent Thickness 4 mm	5.855	0.15%	99.86%
15	Lightweight Steel Roof River Stone / Broken Stone	5.447	0.14%	100.00%
Total Waste Material		**3,951.784**		

An example of the calculation for reinforcing steel material is presented as follows:

$$Percent\ (\%) = \frac{Waste\ Material\ Volume}{Total\ Waste\ Material} \text{ x } 100\%$$

$$= \frac{2{,}102.897}{3{,}951.784} \text{ x } 100\%$$

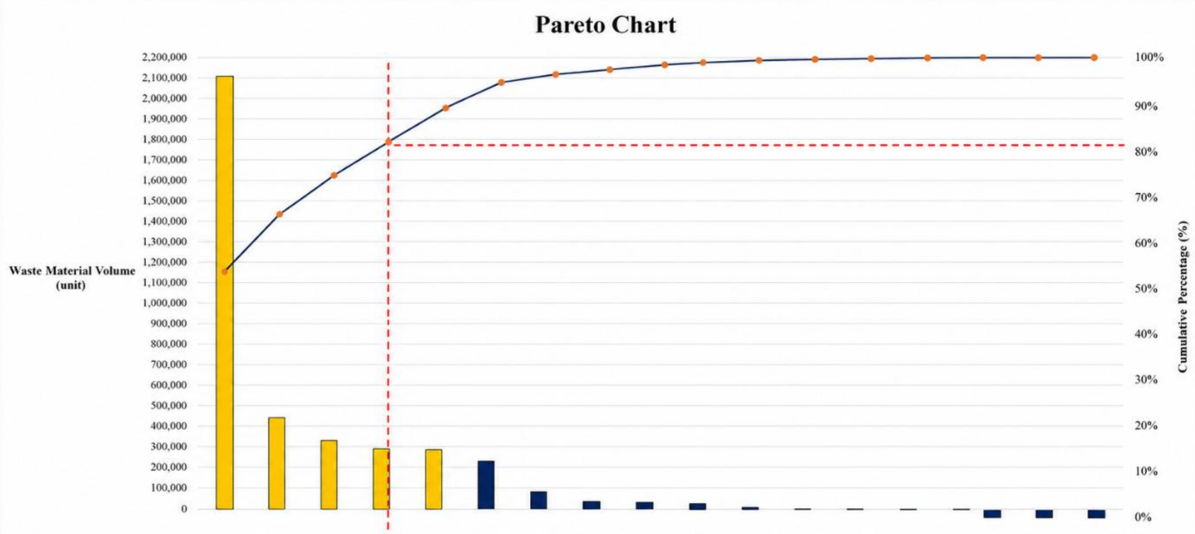
$$= 53{,}21\%$$

The cumulative percentage was calculated by adding the percentage value of reinforcing steel to the percentage value of wall ceramic material as follows:

$$Percent\ Cummulative\ (\%) = \text{Reinforcing Steel Percent} + \text{Wall Ceramic Percent}$$
$$= 53.21\% + 11.38\%$$
$$= 64.59\%$$

It should be noted that several materials, namely the light steel roof frame ex Prima Truss, silver spandek roof sheet, aluminum ridge flashing, and bubble foil insulation, exhibited negative waste values. These negative values indicate that the installed material quantity exceeded the initially planned or available quantity due to technical adjustments and design modifications during project execution. Consequently, these materials did not contribute to material waste generation and the negative values were not considered as dominant waste-contributing materials in the Pareto interpretation because Pareto Analysis focuses on identifying materials with positive waste contributions. Therefore, the determination of dominant waste materials was based exclusively on materials with positive waste values that collectively accounted for approximately 80% of the cumulative waste volume.

Based on the calculation results presented in the table above, the Pareto Diagram can be constructed.



Material	Reinforcing Steel	Wall Ceramic 60 x 60	Lightweight Brick	Floor Ceramic 60 x 60	Plinth Ceramic 10 x 60	Galvanized Hollow Section	Finish Paint	Sand	Primer Paint
Waste Material Volume (unit)	2,102,897	449,714	335,343	296,120	291,918	242,414	86,345	39,343	36,271
Cumulative Percentage (%)	53.21%	64.59%	73.08%	80.57%	87.96%	96.29%	96.28%	97.27%	98.19%

Material	Kalsiboard Fascia Board t= 30 cm	Gypsum 9 mm	Screw Nails	Crushed Stone / Split 2/3	GRC / Equivalent Thickness 4 mm	River Stone / Broken Stone	Lightweight Steel Roof Frame ex Prima Truss / Equivalent C75-0.75	Silver Spandeck Roof ex Prima Deck Thickness 0.35	Aluminum Ridge Flashing Thickness 0.35	Bubble Foil Insulation Thickness 4 mm
Waste Material Volume (unit)	30,060	16,987	6,666	6,444	5,855	5,447	-30,661	-31,929	-32,647	-35.122
Cumulative Percentage (%)	98.95%	99.38%	99.55%	99.71%	99.86%	100.00%	100.00%	100.00%	100.00%	100.00%

Note:
- Positive waste volume indicates materials remaining in the project site or warehouse.
- Negative waste volume indicates that the installed material volume exceeds the initial calculation due to technical adjustments in the field.

Figure 2. Pareto Diagram of Construction Material Waste

In the figure above, the left axis represents the volume of material waste, while the right axis represents the cumulative percentage of the material waste volume. A horizontal line was drawn at the 80% cumulative percentage level until it intersected the cumulative curve. From the intersection point, a vertical line was then drawn downward toward the material axis. Based on the Pareto Diagram, the dominant materials included within the Pareto's Law 80/20 principle are Reinforcing Steel, Wall Ceramic 60 × 60, Lightweight Brick, and Floor Ceramic 60 × 60, as these materials fall within the cumulative percentage of 80%.

Analysis of Factors Causing Dominant Waste Material

The factors causing material waste were identified through unstructured interviews conducted with twenty respondents consisting of contractors and workers involved in the Hermana Lembean General Hospital construction project. These respondents had direct understanding and experience regarding construction implementation processes in the field. The analysis focused on five main categories, namely machine, method, material, manpower, and measurement factors.

The Fishbone Diagram method was applied to identify the factors contributing to material waste and to determine the most dominant causes systematically. Furthermore, all identified factors causing material waste were evaluated through brainstorming sessions involving the respondents. The results of the brainstorming process were then used as the final basis for determining the root causes of material waste occurrence, which were subsequently illustrated in the Fishbone Diagram. The results of the Fishbone Diagram analysis are presented in Figure 3.

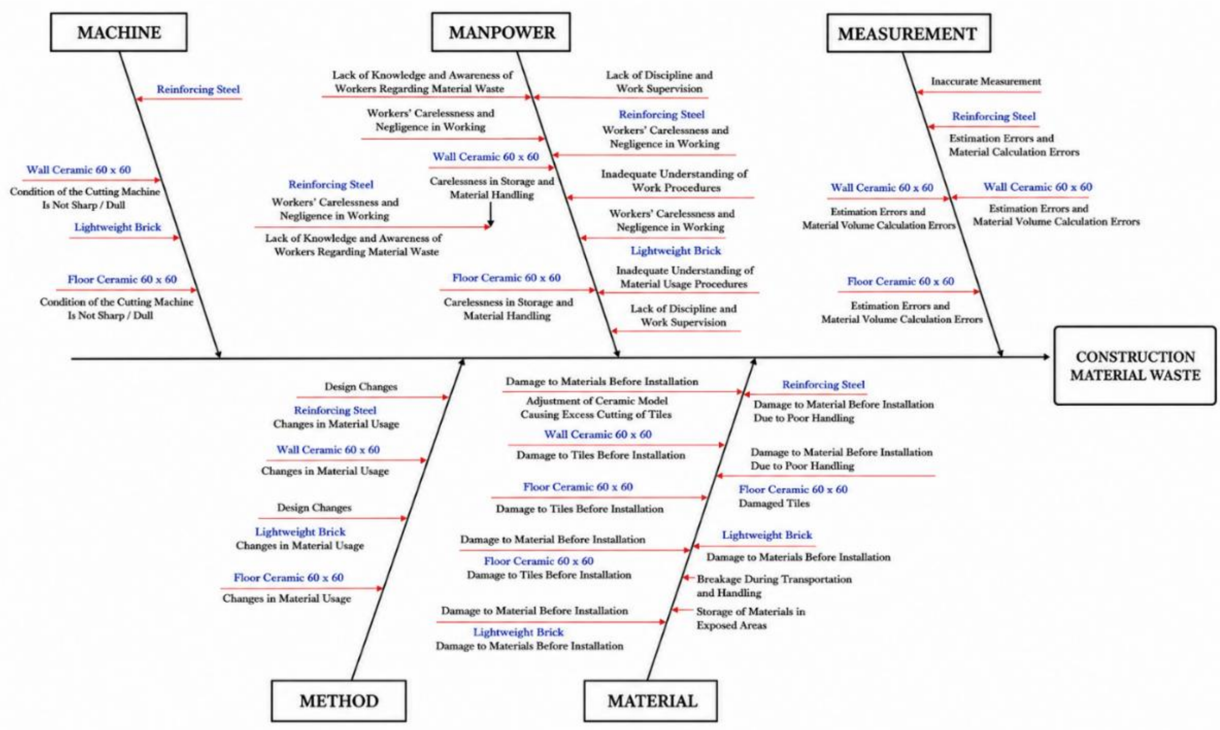


Figure 3. Fishbone Diagram

The Fishbone Diagram analysis revealed that the occurrence of material waste in the Hermana Lembean General Hospital construction project was influenced by five major categories, namely machine, method, material, manpower, and measurement. The identified causes indicate that waste generation is not solely related to material characteristics but is also affected by planning accuracy, work execution, supervision, and material handling practices throughout the construction process. These findings are consistent with previous studies that reported manpower, method, and material management factors as the primary causes of construction material waste. Gultom and Sutandi (2023) found that inadequate supervision, improper work methods, and workers' lack of experience significantly contributed to material waste generation in building construction projects. Similarly, Fitriani (2022) reported that inaccurate material planning, measurement errors, and improper storage systems were among the dominant factors causing waste during project implementation.

The results also support previous studies that recommended the integrated use of Pareto Analysis and Fishbone Diagram for construction waste management. Mokosuli et al. (2023) and Permana Putra et al. (2024) demonstrated that Pareto Analysis is effective in identifying the small number of materials responsible for the majority of waste generation, while Fishbone Diagram provides a systematic approach for identifying the root causes of waste occurrence. Similar findings were observed in the present study, where a limited number of materials, namely reinforcing steel, wall ceramic, lightweight brick, and floor ceramic, contributed to more than 80% of the total positive waste volume. This confirms the applicability of the Pareto principle in construction material waste management.

Furthermore, the Fishbone Diagram analysis revealed that waste generation was influenced by factors related to machine, method, material, manpower, and measurement. These findings are consistent with those reported by Gultom and Sutandi (2023), Fitriani (2022), and Yuliana et al. (2024), who identified planning inaccuracies, inadequate supervision, improper work methods, and material handling deficiencies as major contributors to construction material waste. The consistency of these findings suggests that waste generation is a multidimensional issue requiring integrated management efforts rather than corrective actions focused solely on materials.

Therefore, the integrated application of Pareto Analysis and Fishbone Diagram provides a practical framework for construction waste management. Pareto Analysis assists project managers in prioritizing the materials with the greatest waste contribution, while Fishbone Diagram facilitates the identification of root causes that require corrective actions. The combination of these methods enables more effective decision-making in material planning, procurement, storage, supervision, and utilization, thereby reducing waste generation, improving resource efficiency, and supporting sustainable construction practices.

CONCLUSION

Based on the results of the analysis conducted on the Hermana Lembean General Hospital construction project, several conclusions can be drawn as follows:

1. The total positive construction material waste volume identified in the Hermana Lembean General Hospital construction project was 3,951.784 units. This finding indicates that material waste remains a significant issue that may reduce resource utilization efficiency and increase project costs if not properly controlled.
2. Pareto Analysis revealed that reinforcing steel (53.21%), 60 × 60 cm wall ceramic (11.38%), lightweight brick (8.49%), and 60 × 60 cm floor ceramic (7.49%) were the dominant waste-generating materials. These four materials collectively contributed more than 80% of the total positive waste volume, indicating that waste reduction efforts should prioritize these materials to achieve the greatest improvement in material management efficiency.
3. Fishbone Diagram analysis identified five major categories of factors causing construction material waste, namely machine, method, material, manpower, and measurement factors. The results suggest that material waste is influenced not only by material characteristics but also by planning accuracy, work methods, supervision, worker performance, and measurement practices during project execution.
4. The integration of Pareto Analysis and Fishbone Diagram proved effective in identifying both dominant waste-generating materials and their root causes. This integrated approach can support contractors and project managers in developing targeted waste control strategies, improving material management practices, and enhancing project efficiency.
5. This study contributes to construction management practices by providing an analytical framework for evaluating material waste in building construction projects. The findings may serve as a reference for implementing more effective material planning, monitoring, storage, and utilization procedures.
6. Future studies are recommended to include multiple projects, larger datasets, and additional analytical approaches such as Lean Construction, BIM-based material management, or cost-based waste assessment methods. Such efforts may provide a more comprehensive understanding of construction material waste and support the development of more effective waste reduction strategies.

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