

Evaluation of the Implementation of Environmentally Friendly Material Management in the Green Construction Concept

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ABSTRACT

The rapid growth of Indonesia's construction industry has led to increased construction waste, excessive material consumption, and significant carbon emissions. Construction waste alone contributes up to 40% of total global waste, which, if not managed effectively, results in resource wastage, increased project costs, and environmental harm. This research evaluates the implementation of Green Construction concepts during the construction phase of building projects in Indonesia, identifies factors hindering its implementation, and formulates strategic recommendations for improvement. The study adopts a mixed-method approach, combining quantitative analysis (Likert scale questionnaires of 1–4 based on indicators from the Ministry of Public Works and Housing Circular No. 1 of 2022 and the PUSKIM 2016 rating system) with qualitative analysis through in-depth interviews with project stakeholders. Three building projects with varying certification levels were analyzed: RS Harapan Kita–Tokushukai (LEED Platinum), RS Kanker Dharmais (GreenShip Gold), and Labtek XV ITB (non-certified). Evaluation results indicated that RS Harapan Kita achieved the highest implementation level (average indicator score 3.4/4 or 85%), followed by RS Dharmais (2.8/4 or 70%), and Labtek XV ITB (2.2/4 or 55%). Major implementation barriers identified include weak governmental regulations, insufficient project management commitment, limited availability of certified green materials, and low adoption of digital monitoring technologies on-site. The study recommends strategies to strengthen regulations and government incentives, enhance digital technology utilization (such as BIM), optimize green supply chains, and increase human resource capacity. These findings provide practical input for improving sustainable construction practices in Indonesian building projects.

KEYWORDS



Green Construction, Construction Waste, Sustainable Construction, Green Supply Chain, Materials

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INTRODUCTION

Massive infrastructure development in Indonesia is part of the government's efforts to encourage national economic growth (Nawir, Bakri, & Syarif, 2023). However, behind the acceleration of development, the construction sector also contributes to a negative impact on the environment, especially in terms of material consumption and construction waste production (Purchase et al., 2021). According to Shen and Tam (2002), the construction sector accounts for about 40% of total global waste. In countries such as the United Kingdom, the United States, and Australia, the contribution of construction waste to national waste even reaches more than 35% (Vivian Wing Yan Tam & Lu, 2016). In Indonesia, a similar situation also occurs, especially in high-rise building projects and large infrastructure, where residual materials such as formwork, reinforcing iron, and concrete, are often not managed effectively. More recent data from the Ministry of Environment and Forestry (2023) indicates that construction waste in Indonesia has increased by 15% annually over the past five years, contributing approximately 30% to the total urban waste stream in major cities such as Jakarta and Surabaya. This alarming trend underscores the urgent need for sustainable construction practices in the country (Nguyen Van Tam, 2024).

The problem of construction waste management not only has an impact on the environment, but also triggers inefficiencies in project implementation due to waste of resources and budget overruns (Okonkwo, Evans, & Ekung, 2023). According to Ajayi et al. (2016), waste reduction in the construction sector can only be achieved through a comprehensive strategy that includes the selection of environmentally friendly materials, the application of the principles of recycling and waste separation, and improved logistics management and labor awareness. However, in Indonesia, these efforts still face obstacles in the form of weak regulations, lack of education, and resistance to the adoption of technologies such as BIM and renewable construction methods (Husin et al., 2023).

One of the strategic approaches that is considered effective in responding to environmental challenges in the construction sector is the application of the Green Construction concepts, especially through the management of material use and management that is oriented towards efficiency and sustainability (Cruz, Gaspar, & de Brito, 2019). This concept emphasizes the importance of careful decision-making in the selection, entry, storage, use, and management of residual construction materials so that negative impacts on the environment can be minimized (Erdogan, Šaparauskas, & Turskis, 2019). The application of material management in Green Construction includes various practices, such as the use of materials with a low carbon footprint (e.g. mild steel or EPS), optimization of material volume through technology-based planning (such as BIM and LCA), to structured waste management through the 3R (reduce, reuse, recycle) principle. According to Imran (2018), this strategy not only accelerates the implementation of construction, but is also effective in reducing the potential for waste, reducing additional costs due to excess materials, and increasing logistics efficiency. Thus, material management that is integrated in the Green Construction concepts is one of the key elements in encouraging the achievement of more environmentally friendly and sustainable construction practices in Indonesia (Wibowo, 2024).

Apart from the management and technology aspects, institutional and policy aspects also play an important role (Wu, Liang, & Zhang, 2022). Currently, Indonesia has a Circular Letter of the Minister of PUPR No. 1 of 2022 which provides technical guidelines for assessing the performance of green buildings. However, implementation in the field is still not optimal, especially in the aspect of systematic material and waste management (Alshaikh & Abdelfatah, 2024). As a complement, the rating system from the Center for Housing and Settlement Research and Development (PUSKIM, 2016) also provides sustainability indicators that focus on material use efficiency, resource conservation, and waste reduction.

Through this understanding, it is important to conduct an evaluative study of the implementation of Green Construction concepts in the use and management of materials in construction projects (Lu, Chi, Bao, & Zetkalic, 2019). This research will not only identify the extent to which the concept of Green Construction has been applied, but will also evaluate the gap between actual conditions on the ground and the ideal standards set in national policies. Thus, this research is expected to make a real contribution in formulating a Green Construction application strategy that is more effective and adaptive to project conditions in Indonesia (Sedayu, Setiono, Subaqin, & Gautama, 2020).

The formulation of the problem in this study departs from the fact that the construction sector in Indonesia is still a significant contributor to waste generation and carbon emissions, most of which are sourced from the selection, use, and management of materials that are not

optimal and not environmentally friendly. The Green Construction concepts is present as a strategic solution to overcome these problems through resource use efficiency, waste reduction, and environmental impact control throughout the project life cycle (Nwaogbe, Urhoghide, Ekpenyong, & Emmanuel, 2025). However, the implementation of this concept still faces various obstacles, ranging from the limitations of mandatory regulations governing specifications and standards for green materials, uneven distribution of materials, to the lack of competence of human resources in understanding and implementing sustainability principles. Therefore, the main problems raised in this study are how the level of application of the Green Construction concepts in terms of material use and management in actual construction projects, what are the challenges faced in its implementation, and how the gap between the ideal conditions as stated in the Circular Letter of the Minister of PUPR No. 1 of 2022 and the 2016 PUSKIM Green Building Rating System with real practices in the field. This research also questions what strategies can be formulated to encourage the increased application of Green Construction principles in supporting the creation of more adaptive and applicable sustainable construction in Indonesia (Adhi & Muslim, 2023).

Based on the formulation of the problem above, this research aims to: (1) identify the level of application of the Green Construction concepts in the review projects as well as the obstacles and challenges faced in its implementation; (2) evaluate the suitability of the application of the Green Construction concepts in the review projects to ideal conditions based on applicable regulations; and (3) formulate recommendations for strategies for the implementation of the Green Construction concepts to improve sustainable construction practices in the review projects.

The benefits of this research are threefold. First, theoretically, this study contributes to the body of knowledge on sustainable construction practices by providing empirical evidence on the implementation gaps between regulatory standards and field practices in developing countries. Second, practically, the findings offer actionable strategies for construction practitioners, project managers, and contractors to enhance their green construction implementation. Third, for policymakers, this research provides data-driven recommendations to strengthen regulations, develop incentive mechanisms, and improve the green material certification system in Indonesia.

METHOD

This study used mixed methods, combining qualitative and quantitative approaches to systematically collect and analyze data. This approach was chosen to gain a comprehensive understanding of the application of the Green Construction concept, focusing on the use and management of environmentally friendly materials. The three public building projects analyzed were selected to represent variations in the application of the Green Construction concept in Indonesia: Dharmais Cancer Hospital, targeting Greenship Gold certification from the Green Building Council Indonesia (GBCI); Harapan Kita-Tokushukai Hospital, targeting LEED Platinum certification based on international standards; and Labtek XV ITB, which implemented Green Construction principles internally without formal certification targets.

The data collection involved three methods. First, a questionnaire was developed based on indicators from Minister of PUPR Decree No. 1 of 2022 and the 2016 PUSKIM Rating

System, using a Likert scale from 1 to 4 to measure the level of Green Construction implementation. Second, semi-structured in-depth interviews were conducted with project stakeholders to explore material implementation practices in detail. Third, direct field observations took place at the project sites to verify the data collected through questionnaires and interviews.

For data analysis, quantitative data were processed using the Relative Importance Index (RII) to determine the significance of factors inhibiting implementation. Qualitative data were analyzed descriptively to identify gaps between ideal conditions and actual practices. Triangulation of these data sources was applied to improve the validity and reliability of the study's findings.

RESULT AND DISCUSSION

Implementation Level Results Analysis

In this section, an analysis will be carried out on the results of data processing that has been carried out in Chapter IV.2 related to the level of application of Green Construction in the use and management of materials in construction projects that are the object of research. This analysis aims to assess the extent to which the principles of Green Construction have been applied in the selection, use, and management of materials in the review project based on the results of questionnaires and interviews that have been collected.

The results of the questionnaire that have been processed previously provide a quantitative overview of the implementation of the Green Construction indicator, which includes aspects of the green construction process and green supply chain. These indicators have been compiled based on SE PUPR and PUSKIM as well as previous research references, so that the analysis carried out has a strong and measurable basis. Using the Likert scale, each aspect of the implementation was assessed based on the respondents' perceptions of each project, which was then compared with in-depth interviews to gain a more holistic understanding of implementation in the field.

The analysis was carried out on three review projects, namely Dharmais Cancer Hospital, Labtek VX ITB, and Harapan Kita - Tokushukai Hospital, each of which has a different level of implementation of Green Construction. The evaluation highlights areas that have been well implemented and identifies areas that still need improvement, particularly in the use and management of materials and the efficiency of their supply chains. By comparing the three projects that have different scales, functions, and levels of complexity, this study is expected to provide insight into the effectiveness of Green Construction implementation in various types of construction projects in Indonesia. The following is an analysis of the level of implementation for each project.

1) Dharmais Cancer Hospital Project

This analysis aims to evaluate the level of application of the Green Construction concept in the Dharmais Cancer Hospital project, focusing on the management of the use and management of construction materials. The evaluation was carried out based on three main variables, namely: (1) Implementation of Construction Waste Management (Green Construction Process), (2) Use of Construction Materials, and (3) Selection of Suppliers/Subcontractors (Green Supply Chain). These three variables are compiled based on

indicators from the 2016 PUSKIM Green Building Rating System which is then strengthened and detailed through technical references from the Minister of PUPR Decree No. 1 of 2022. This assessment is also supported by the academic literature from, Tjokorda et al. (2023), Setyowati et al. (2014), and Praganingrum et al. (2023) to strengthen the indicator framework and the relevance of practice in the field.

2) Labtek XV ITB Project

This analysis aims to evaluate the level of application of the Green Construction concept in the Labtek XV ITB project, focusing on the management of the use and management of construction materials. The evaluation was carried out based on three main variables, namely: (1) Implementation of Construction Waste Management (Green Construction Process), (2) Use of Construction Materials, and (3) Selection of Suppliers/Subcontractors (Green Supply Chain). These three variables are compiled based on indicators from the 2016 PUSKIM Green Building Rating System which is then strengthened and detailed through technical references from the Minister of PUPR Decree No. 1 of 2022. This assessment is also supported by the academic literature from, Tjokorda et al. (2023), Setyowati et al. (2014), and Praganingrum et al. (2023) to strengthen the indicator framework and the relevance of practice in the field.

3) Harapan Kita Hospital Project – Tokushukai

This analysis aims to evaluate the level of application of the Green Construction concept in the Harapan Kita – Tokushukai Hospital project, with a focus on the management of the use and management of construction materials. The evaluation was carried out based on three main variables, namely: (1) Implementation of Construction Waste Management (Green Construction Process), (2) Use of Construction Materials, and (3) Selection of Suppliers/Subcontractors (Green Supply Chain). These three variables are compiled based on indicators from the 2016 PUSKIM Green Building Rating System which is then strengthened and detailed through technical references from the Minister of PUPR Decree No. 1 of 2022. This assessment is also supported by the academic literature from, Tjokorda et al. (2023), Setyowati et al. (2014), and Praganingrum et al. (2023) to strengthen the indicator framework and the relevance of practice in the field.

Analysis of Inhibitory Factors Results

In this subchapter, we will discuss in detail the inhibiting factors that have passed the validity and reliability test, which play a role in hindering the application of material use and management in the Green Construction concept. Each factor will be analyzed based on the data obtained from the results of the questionnaire, and reinforced with the findings of interviews and literature studies to provide a deeper understanding of the challenges faced in the implementation of this concept in construction projects.

The discussion of these inhibiting factors will be arranged according to the order of the factor codes that have been categorized. However, before entering the analysis of each factor, an influence classification will be carried out using the Relative Importance Index (RII) method to determine the level of significance of each factor tested. This classification aims to identify whether an indicator has a significant influence on the implementation of Green Construction

or is only a minor obstacle that does not have much impact on project implementation. The following is a classification of the level of influence of the Republic of Indonesia carried out.

Table 1 Classification of the Influence of the Republic of Indonesia

Classification of the Influence of the Republic of Indonesia			
Value Range RII			Class Classification
0,25	-	0,4375	Very Unaffected
0,4375	-	0,625	Not Influential
0,625	-	0,8125	Influential
0,8125	-	1	Highly Influential

(Source: Author's Data Processing)

The table above refers to the theory of the RII Analysis Assessment Criteria by Sugiyono (2018) and because the likert scale used is 4 with a minimum value of RII is 0.25, the range can be determined as 0.1875. After determining the assessment criteria, the following is a recapitulation of the level of influence of inhibitory indicators in the concept of Green Construction.

Table 2. Results of the Classification of the Influence of RII

Code	Inhibiting Factors	LITTLE Factor	Ranking Factor	Classification of Influence
P1	Lack of mandatory regulations on specifications, certifications, and standards for the use of environmentally friendly materials in construction projects.	0,840	1	Highly Influential
P10	The distribution of green materials is still limited and not widely available, leading to a reliance on conventional materials.	0,833	2	Highly Influential
P5	Lack of certification of green materials that are nationally recognized and used as a requirement in construction projects.	0,819	3	Highly Influential
P8	The cost of procuring environmentally friendly materials is still higher than conventional materials due to limited supply.	0,813	4	Highly Influential
P15	The green material manufacturing industry is still limited, leading to high production costs and a lack of material options available.	0,799	5	Influential
P9	High cost risks due to uncertainty about the success of new technologies in the use of green materials.	0,792	6	Influential
P2	There is no standard guideline for the management of construction material waste that can be applied consistently to all projects.	0,778	7	Influential
P17	The civil engineering and architectural curriculum has not taught much about methods and standards for the use of friendly materials milieu.	0,757	8	Influential
P4	Lack of socialization and education related to the benefits and effectiveness of using green materials in construction projects.	0,743	9	Influential
P12	Lack of manpower skills in managing and implementing green materials effectively in construction projects.	0,736	10	Influential
P16	Lack of training on the specifications, application methods, and benefits of green materials in construction.	0,715	11	Influential
P13	The lack of processing and recycling facilities for construction materials so that their use has not become standard in the project.	0,694	12	Influential
P21	The adoption rate of green materials is still low because workers and contractors are more accustomed to using conventional materials.	0,618	13	Not Influential
P3	There is a lack of regulations that regulate incentives for companies that use green materials in construction projects.	0,611	14	Not Influential

P7	There is no government support in the form of subsidies or cheap credit to support the application of green materials in construction.	0,604	15	<i>Not Influential</i>
P11	Lack of quality standards and standardized testing mechanisms for green materials before use in construction projects.	0,549	16	<i>Not Influential</i>
P20	Lack of monitoring and evaluation system application of green materials in construction projects.	0,528	17	<i>Not Influential</i>

(Source: Author's Data Processing)

Based on the table above, the results of the influence classification using the RII method, obtained 4 factors with the category "Highly Influential" and 8 factors with the category "Influential", which shows that these factors have a significant impact on obstacles in the application of materials in construction projects. Meanwhile, there are 5 factors with the category "Not Affected", which shows that these factors do not have a significant impact on the constraints of using green materials. Therefore, further analysis will only focus on factors that fall into the "Highly Influential" and "Influential" categories, as these factors have an important role in determining strategies and solutions that can be applied to improve material utilization in construction projects. The following is an analysis of the inhibiting factors sorted based on the ranking of the RII factors of each indicator.

- 1) Lack of mandatory regulations on specifications, certifications, and standards for the use of environmentally friendly materials in construction projects
- 2) The distribution of green materials is still limited and not widely available, leading to a reliance on conventional materials
- 3) Lack of nationally recognized green material certification and used as a requirement in construction projects
- 4) The cost of procurement of environmentally friendly materials is still higher than conventional materials due to supply constraints
- 5) The green material manufacturing industry is still limited, leading to high production costs and a lack of material options available
- 6) High-cost risk due to uncertainty about the success of new technologies in the use of green materials
- 7) There is no standard guideline for the management of construction material waste that can be applied consistently to all projects
- 8) The civil engineering and architectural curriculum have not taught much about the methods and standards of using environmentally friendly materials
- 9) Lack of socialization and education related to the benefits and effectiveness of using green materials in construction projects
- 10) Lack of manpower skills in managing and implementing green materials effectively in construction projects
- 11) Lack of training on the specifications, application methods and benefits of green materials in construction
- 12) Lack of facilities for processing and recycling construction materials so that their use has not become standard in projects

Implementation Strategy Recommendations

Evaluation of the Implementation of Environmentally Friendly Material Management in the Green Construction Concept

Analysis of Green Construction implementation across three projects revealed varying levels of compliance with established standards. To address these findings strategically, recommendations were classified into three tiers: "Compliant" for optimally implemented indicators, "Less Appropriate" for partially met criteria, and "Non-Compliant" for unexecuted indicators. This classification ensures contextual and operational strategies, where ideal conditions require strengthening and compliant projects need fundamental improvements. The strategy formulation was based on method triangulation, gap analysis against SE PUPR and PUSKIM standards, and a literature study emphasizing managerial approaches, while also considering bottlenecks from regulatory to cultural aspects.

To verify the proposed strategies' relevance and realism, validation was conducted with PT PP's Green Department, the main contractor for two reviewed projects. This provided critical input on the strategy's field applicability and alignment with company policies. For the Labtek XV ITB project by PT Wika Gedung, direct validation wasn't performed as the research is generic and comparative rather than a singular evaluative study. Validating with one major contractor was deemed sufficient to reflect general field needs while maintaining representation of Green Construction practices in Indonesia.

The resulting implementation strategies address specific gaps in material use and management. For instance, while all projects perform material optimization, none fully comply with waste calculation simulation requirements, necessitating BIM and Life Cycle Assessment integration. Similarly, although domestic material usage exceeds 40% minimum, reliance on imported MEP and finishing systems persists, requiring enhanced TKDN supervision and local material substitution. Other key strategies include implementing digital waste reporting systems, establishing policies for certified green materials, limiting heavy equipment age for energy efficiency, and reducing packaging waste through returnable systems. These targeted strategies are designed to bridge the gap between ideal standards and field practices for more effective Green Construction application.

Dharmais Cancer Hospital Project

Green Construction Process (Implementation of Waste Management Management)

The project has successfully optimized material usage to minimize construction waste by employing high-durability materials and leveraging digital tools like BIM 6D for monitoring, which prevents over-ordering and tracks residual materials. Although this practice enhances resource efficiency and aligns with technological advancements in the field, it still falls short of fully complying with PUSKIM and SE PUPR standards due to the absence of formal waste calculation simulations. Therefore, the strategic recommendation is to integrate these simulations with BIM and Life Cycle Assessment (LCA) tools to ensure that material usage has a minimal environmental impact moving forward.

In the area of waste management, the 3R system (Reduce, Reuse, Recycle) has been effectively executed, with waste being sorted into categories such as organic, inorganic, and hazardous materials. Practices like reusing wooden formwork and repurposing leftover concrete for non-structural components are fully in line with regulatory requirements. Since this indicator is considered compliant, the strategic focus shifts to maintaining consistency through continuous worker training and periodic monitoring, ensuring that these effective waste sorting and reuse practices are upheld without needing major corrective actions.

For material storage, the project maintains a well-organized system where materials are stored according to type and specific requirements, such as keeping cement in enclosed spaces and steel in corrosion-resistant areas. A manual tracking system is in place to log incoming materials, which successfully reduces potential damage and loss. As this practice already meets the established standards, the recommended strategy is to sustain these good practices while potentially enhancing them by adopting technologies like QR codes or RFID for more efficient inventory management and regular warehouse inspections.

However, a significant gap remains in the formal reporting of construction waste recycling activities. While the project substantively applies recycling principles, the lack of a documented reporting system makes it difficult to measure the effectiveness of these efforts and violates specific SE PUPR indicators. To address this, the project is advised to establish a formal 3R reporting protocol that records and evaluates recycled waste volumes. Integrating this with specialized software or BIM modules would create the necessary structured monitoring, fulfil documentation requirements and enabling systematic improvement of recycling initiatives.

Green Supply Chain (Construction Material Use)

The Dharmais Cancer Hospital project demonstrates a strong commitment to utilizing local materials, with a Domestic Component Level (TKDN) of 60% that significantly exceeds the mandatory 40% threshold. This practice supports local industries and substantially reduces the carbon footprint associated with material transportation. Since this indicator is fully met, the strategic focus is on maintenance and slight improvement, such as ensuring that these local materials also possess standard certifications like SNI to maintain quality while continuing to prioritize local vendors.

In the selection of eco-friendly materials, the project has taken proactive steps by incorporating fly ash concrete, low-VOC paints, and insulated sandwich panels. These choices reduce carbon emissions from material production and improve indoor air quality, aligning with green building regulations and performance goals. As these practices are already compliant, the future strategy is to continue innovating by seeking new green alternatives, despite the cost challenges, and to potentially propose financial incentives to bridge the price gap for long-term sustainability.

The procurement and delivery of materials are efficiently managed through a Just-In-Time (JIT) system, where materials are delivered in phases according to the construction schedule, minimizing accumulation and potential damage. A digital logistics system supports this by monitoring material flow to ensure timely arrival and usage. With this indicator operating optimally, the recommended strategy involves minor enhancements, such as implementing further tracking to monitor emissions from transportation and optimizing delivery routes to further reduce the carbon footprint.

However, the management of heavy equipment presents a significant gap in sustainability, as there are currently no age or emission restrictions for the machinery used. This allows for the operation of old, inefficient units with high emissions, making this indicator non-compliant with green construction guidelines. The necessary strategy is twofold: implementing a policy that sets a maximum age or emission standard for equipment and

establishing real-time monitoring of fuel consumption and emissions to identify and rectify inefficient machinery.

Similarly, the reduction of material packaging waste is an area that has not yet met standards, with most materials arriving in single-use packaging that ends up as waste. Although limited efforts like bulk cement delivery exist, a comprehensive reverse logistics system for returning packaging to suppliers is not in place. To achieve compliance, an aggressive strategy is required, mandating the use of bulk or reusable containers and implementing a formal system for returning empty packaging to manufacturers for recycling or refilling, thereby advancing towards a circular economy model.

Green Supply Chain (Supplier Selection)

The Dharmais Hospital project excels in selecting local suppliers, with over 50% of its material needs sourced from within a 10 km radius, including a concrete batching plant just 2 km away. This ideal implementation minimizes transportation emissions and logistics costs. The strategic recommendation is to further optimize this strength by implementing systems to track fleet fuel emissions, which would allow for quantitative performance measurement and identify additional opportunities for emission reductions, such as load consolidation or optimized delivery schedules.

For the indicator requiring the use of domestically made materials, the project has achieved compliance in structural materials but still relies on imports for specialized architectural and MEP equipment due to limited local availability that meets high technical specifications. The strategy to close this gap is two-fold: internally, the project should tighten its supplier selection by giving preference to those with green certifications like ISO 14001, and externally, it should advocate for government policies and incentives that boost the capacity and certification of the local green industry. This combined approach encourages the use of existing local green products while fostering the development of new ones to replace imports.

Labtek XV ITB Project

Green Construction Process (Implementation of Waste Management Management)

a. A1 – Optimization of Material Usage

The project has optimized the use of materials to minimize construction waste. For example, a modular system is used for the construction of keel directors, so that waste is reduced and resource efficiency increases. Because the practice is still not in accordance with PUSKIM and SE PUPR standards, the future strategy is focused on implementing a waste calculation simulation integration system in optimization methods with BIM and Life Cycle Assessment (LCA) to ensure that the materials used have minimal environmental impact. Projects are recommended to use BIM and other planning tools to ensure efficient use of materials.

b. A2 – Construction Waste Management and Waste Sorting

The 3R (Reduce, Reuse, Recycle) system has been well executed. Waste is sorted into organic, inorganic, and B3; Wooden formwork is reused, and the remaining concrete is used for non-structural components. The project also works with licensed transporters to handle B3 waste, in accordance with regulations (PP No. 101/2014). This implementation is in accordance

with the SE PUPR standards (indicators B.3.a & B.3.b) and PUSKIM (C2) which require waste sorting. These results reflect the literature's recommended sustainability practices, where systematic waste sorting can reduce total waste by up to 40%. Because it is appropriate, the focus of the strategy is to maintain consistency. The project needs to ensure workers continue to be trained in effective waste sorting as recommended by Rahmawati et al. (2022) and maintain the 3R commitment in the field. This means that there is no need for a large corrective strategy, just periodic monitoring so that waste sorting and reuse continue to run optimally.

c. A3 – Safe and Organized Material Storage

The project has innovated in material storage management by implementing a QR Code and MSDS-based inventory system. Each material that comes is coded and recorded its storage location, so that the stock can be easily tracked and avoided from accumulation or loss. Materials are stored separately according to their type (metal, non-metal, B3, etc.), as well as the storage area of B3 materials is separated to prevent cross-contamination. This approach meets the rules of safe storage in accordance with the SE PUPR (indicator B.3.c) and PP Regulation No. 101/2014 for the handling of hazardous materials. The positive impact is reduced risk of damage to materials before use and time efficiency when sourcing materials. Because this A3 indicator is up to standard, the strategy is focused on continuity and minor improvements. Projects should continue to use the QR Code and MSDS systems and conduct periodic audits to ensure accurate inventory data. If possible, integration with project systems (e.g. integrated project management applications) can be carried out so that stock information, usage, and material re-orders can be monitored by management in real-time. With this strengthening, Labtek XV can maintain good performance in the aspect of material storage.

d. A4 – Construction Waste Recycling

In substance, the project has applied the principle of recycling, for example the reuse of formwork and the use of residual concrete for minor works. However, there is no formal reporting system for these recycling activities. The absence of documentation makes it difficult to measure the effectiveness of 3R efforts and is a weakness to the B.3.d SE PUPR indicator which requires waste reporting. In other words, the implementation of A4 is still poorly documented. This gap is common because many projects in Indonesia do not have standard procedures for recycling monitoring and often only dispose of waste in landfills without sorting or recording. To bridge the gap, an integrated waste management strategy is needed. Projects are advised to set up a 3R reporting protocol, each volume of recycled waste is recorded, reported and evaluated. In addition, integration with technology can be considered, for example using BIM modules or special applications for tracking recycled waste. This will meet the documentation requirements as emphasized by PUSKIM, and in line with the recommendation of Rahman et al. (2019) that structured monitoring is needed so that recycling efforts can be systematically improved.

Green Supply Chain (Construction Material Use)

a. B1 – Use of Materials with High TKDN

The Labtek XV ITB project does not have a strict policy regarding TKDN because of its status as an educational institution project, not a government project bound by Presidential Decree No. 12 of 2021. However, in practice, most of the main materials such as concrete,

reinforcing steel, and ceramics are indeed supplied from local producers in Indonesia. This has contributed to reducing transportation emissions and supporting the national economy. To improve the fulfillment of this indicator, implementation strategies that can be carried out include setting internal TKDN targets, for example, a minimum of 50% of material value comes from within the country, as an initial benchmark. This strategy aims to encourage procurement teams to be more active in finding local alternatives, even though this project is not required to follow formal TKDN regulations. In addition, it is necessary to identify components that still need to be imported, such as glass facades and MEP equipment, and to examine the possibility of substitution of local products, although architectural design adjustments may be required. If substitution remains not possible, then other alternatives such as carbon offset programs can be implemented to balance out the impact. The next step is to encourage policies from institutions that support the use of domestic products so that the effect of implementing these policies can strengthen the project's position on the principles of Green Construction. This is in line with the results of research by Widyaningsih et al. (2022) who stated that the existence of regulations affects the level of application of local materials in infrastructure projects.

b. B2 – Selection and Use of Eco-Friendly Materials

Implementation at Labtek XV is still very limited. Only a few initiatives have been carried out, such as the use of modular panels for keet directors that can be reused in other projects, but most of the structural and finishing materials are still based on conventional materials such as ordinary concrete, new steel, and there has been no application of paint or ecolabel certified materials. The main obstacles faced by the project team were the availability of green materials that complied with technical specifications and the higher cost of ordinary materials, which is still a common problem in construction projects. To improve this, the first step is to conduct an inventory and study of alternative green materials that can be adopted technically and financially, such as the use of slag-mixed concrete, partition panels from recycled materials, or paint with environmentally friendly labels. The next step is to provide training to the project's technical team so that they understand the benefits and how to apply green materials, considering that Rahmawati et al. (2022) noted that one of the causes of low adoption of green materials is the lack of understanding among engineering professionals. Finally, financial support or incentives from project management can be very helpful in offsetting the difference in the price of green materials. Widyaningsih et al. (2022) also emphasized that training has been proven to be able to increase the effectiveness of using environmentally friendly materials by up to 40%.

c. B3 – Use and Delivery of Materials

The Labtek XV project has successfully implemented a just-in-time (JIT) approach, where materials are delivered in stages according to the schedule of actual needs in the field. This not only helps reduce the risk of material damage due to storage for too long, but also supports the lean principle in construction. The project has also used a digital monitoring system to manage the entry and exit of materials more accurately. This practice is very much in line with the principle of supply chain efficiency in PUSKIM and SE PUPR. The strategy that can be done is to continue to evaluate data from the monitoring system to find efficiency gaps, such as identifying the types of materials that often experience overstock or residual

waste. Further coordination with vendors to regulate the frequency and volume of deliveries can also be done to make material distribution more optimal and low emission.

d. B4 – Use and Delivery of Heavy Equipment

The Labtek XV project has considered the efficiency of heavy equipment through limiting operating hours to minimize noise in the campus area and by monitoring the diesel fuel consumption of each tool. However, there is no formal policy regarding emission standards or age limits for heavy equipment, so it is still possible to use obsolete and high-emission heavy equipment. To improve the performance of this indicator, the project needs to implement a policy of selecting heavy equipment with a maximum age of 10 years and meeting Tier 3 or Euro IV emission standards as applied to the RS Harapan Kita project. In addition, the fuel consumption data that has been collected should be further analyzed to assess energy efficiency and carbon emission estimates. Hosseini et al. (2020) emphasized that real-time monitoring of fuels and emissions has proven to be effective in driving efficiency and supporting decarbonization efforts in the construction sector.

e. B5 – Packaging Packaging Material

This indicator is one of the weak points in the XV Labtek Project. The majority of materials come in single-use packaging without any reuse efforts, returns to suppliers, or systematic recycling mechanisms. Packaging waste is only sorted by type (plastic, metal, paper) before being disposed of. The improvement strategy is to include the requirements of eco-friendly packaging or bulk delivery in the material purchase contract, for example using bulk cement in a silo instead of ordinary cement bags. Onsite facilities also need to be provided to maintain the condition of used packaging so that it can be returned to suppliers. Reverse logistics programs that involve suppliers in the process of picking up or exchanging used packaging can be an effective solution. According to Rahman et al. (2019) and Zhang et al. (2019), the implementation of circular logistics systems and refillable packaging can significantly reduce waste and support circular economy principles which are an important part of Green Construction.

1. Green Supply Chain (Supplier Selection)

a. C1 – Materials and Tools Suppliers Close to Project Addresses

This project is good enough because most of the main materials and heavy equipment are obtained from suppliers in the Bandung area with an average delivery distance of ≤ 10 km. This distance is far below the ideal limit of ≤ 200 km set by the SE PUPR. Thus, this indicator is appropriate. For future optimization, the strategy that can be done is to combine the delivery of several types of materials in one trip and evaluate the delivery from more distant locations to encourage the development of new suppliers around the campus. This is also in line with Tjokorda et al. (2023) who emphasized the importance of local logistics resilience in supporting sustainable construction.

b. C2 – Suppliers of Materials and Tools Made in Indonesia

The Labtek XV project has indeed used various domestic products such as concrete, light bricks, and reinforcing steel, but not all products have certifications such as SNI or ecolabel. Some components such as MEP equipment also still have to be imported. A strategy that can be implemented is to develop a supplier selection procedure based on ownership of environmental certification (SNI, ISO 14001, or ecolabel), as well as include emission

compensation measures for imported items, such as tree planting programs or other carbon reductions. On the other hand, the project can also collaborate with research institutions to develop local substitution products that are in accordance with technical standards. Hosseini et al. (2020) and Dwaikat & Ali (2018) both emphasize the importance of government policies and industry incentives to improve.

Harapan Kita Hospital Project – Tokushukai

Green Construction Process (Implementation of Waste Management Management)

a. A1 – Optimization of Material Usage

The Harapan Kita Hospital project showed excellent application by adopting prefabricated materials in the form of sandwich panels instead of conventional brick walls. This innovation not only reduces waste, but also makes it easier to re-dismantle and reduce the volume of construction waste. On the other hand, the use of software such as SCOP and OptiCut for the optimization of the cutting of reinforcing steel allows for significant material efficiency. This practice is in line with the findings of Tjokorda et al. (2023) who emphasize the importance of digitizing material management in green construction. Because the practice is still not in accordance with PUSKIM and SE PUPR standards, the future strategy is focused on implementing a waste calculation simulation integration system in optimization methods with BIM and Life Cycle Assessment (LCA) to ensure that the materials used have minimal environmental impact. Projects are advised to continue to use BIM and other planning tools to ensure that the use of materials remains efficient.

b. A2 – Construction Waste Management and Waste Sorting

The project has implemented a system of sorting waste from the source, distinguishing between household waste, construction waste, and B3 waste. This is in line with Government Regulation No. 27 of 2020 which requires a waste sorting system before final disposal. The project also collaborates with a licensed third party for the transport of B3 waste, demonstrating compliance with hazardous waste management regulations. The advanced strategy focuses on upgrading the program to zero-waste to landfill, by ensuring the majority of waste can be recycled or reused. This also reinforces the effectiveness of the 3R principle as emphasized by Rahmawati et al. (2022), who underscore the importance of sorting and recycling from the early stages of the project to improve overall environmental performance.

c. A3 – Safe and Organized Material Storage

The project has met high standards by separating materials according to their type as well as providing dedicated storage areas for hazardous materials. Warehouse inspection activities are carried out periodically to ensure safe and tidy storage, in line with the provisions of Government Regulation No. 101 of 2014 concerning B3 Waste Management. The next strategy is quite maintenance-based, but the project could adopt stock tracking technologies such as barcodes or QR to improve the efficiency of inventory management. This culture of discipline in storage must be maintained, and monthly evaluations can be used to ensure that there is no damage/loss of material due to negligence in warehouse management.

d. A4 – Construction Waste Recycling

The Harapan Kita Hospital project has succeeded in implementing the 3R principle in real life by utilizing excavated waste as a waste material, as well as documenting this recycling practice regularly in the project report. This approach is in accordance with the Minister of

PUPR Regulation No. 9 of 2021 and the guidelines from PUSKIM which emphasize the importance of recording recycling activities as part of the continuous improvement process. The strategy going forward is to expand the types of waste that can be recycled (such as concrete or gypsum) and establish an internal reward system for teams that manage to increase the proportion of recycling. This is also in line with the opinion of Rahman et al. (2019) who mentioned that waste reporting is an important step for systematic improvement in construction waste management.

1. Green Supply Chain (Construction Material Use)

a. B1 – Use of Materials with High TKDN

The project has met the requirement of at least 50% of materials coming from within the country, as stipulated in Presidential Regulation No. 12 of 2021. The main materials such as precast concrete, structural steel, and wall panels are supplied from local manufacturers. Meanwhile, for MEP components that are still imported, the project runs an emission compensation program through reforestation. The next implementation strategy is to maintain the consistency of using local materials in additional work, as well as encourage technology transfer cooperation so that imported components can be produced in Indonesia in the future. This is in line with the direction of SE PUPR regarding reducing the carbon footprint of the supply chain through local innovation and offset policies.

b. B2 – Selection and Use of Eco-Friendly Materials

The project has been implemented quite well, with the use of high-insulated sandwich panels that reduce the structural load and energy consumption of the air conditioner, as well as the use of low VOC paint that maintains the air quality in the room. This implementation is in accordance with the provisions of PUSKIM and SE PUPR which prohibit the use of materials containing hazardous substances such as high VOCs, mercury, or asbestos. The next strategy is to add a variety of green materials such as recycled floors or the use of rainwater recycling systems. Projects can also conduct energy performance evaluations to demonstrate the effectiveness of using environmentally friendly materials quantitatively, as Dwaikat & Ali (2018) study in the context of proving the economic benefits of green materials.

c. B3 – Use and Delivery of Materials

The RS Harapan Kita project has been running optimally with the implementation of a just-in-time system for material delivery and storage. This approach helps reduce the risk of material damage and supports transportation efficiency, while reducing carbon emissions. The use of local suppliers and emission offsets for imported materials shows a high level of concern for the concept of a low-carbon supply chain, according to the IEA (2022) guideline which calls this approach to reduce carbon emissions by up to 30%. The next strategy is to make this practice a formal SOP so that it can be replicated in other projects, and to monitor the effectiveness of offsets through the calculation of estimated emission absorption.

d. B4 – Use and Delivery of Heavy Equipment

The project has an excellent policy of limiting the life of the machine to a maximum of 10 years and requiring real-time fuel monitoring using a fuel efficiency monitoring system. This step is in line with the Minister of PUPR Regulation No. 9 of 2021 and the recommendations of the World Green Building Council (2021) which emphasizes the importance of efficient and local heavy equipment selection. The next strategy is to ensure that

all subcontractors are also compliant with the tool age policy, as well as to consider testing the use of biofuel or electric-heavy equipment for further emission reductions. Weekly evaluations of fuel consumption can be used for additional control to maintain operational efficiency.

e. B5 – Packaging Packaging Material

The project is still experiencing weaknesses because many materials come in single-use packaging and no reuse or reverse logistics system has been implemented. This causes about 25% of construction waste to come from material packaging. The improvement strategy is to choose suppliers who provide bulk packaging or reusable packaging options, implement an internal policy to reduce packaging, and build cooperation with suppliers for the recovery of empty packaging. Rahman et al. (2019) and Zhang et al. (2019) stated that circular logistics and the use of refillable packaging can support the circular economy as well as significantly reduce waste volume. These measures can bring the B5 indicator from an inappropriate condition to a partial implementation.

2. Green Supply Chain (Supplier Selection)

a. C1 – Materials and Tools Suppliers Close to Project Addresses

The selection of local suppliers is the strength of this project. Since it is in Jakarta, Harapan Kita Hospital utilizes many suppliers who are very close to the project. For example, the concrete batching plant from Taman Anggrek is only 2 km from the location and the heavy equipment vendor is in the Jakarta industrial area. More than 50% of material requirements are supplied from within a <10 km radius that complies with regulations for green supply chains. As a result, transportation emissions have decreased, and logistics costs have become more efficient. Because the implementation is ideal, there are not many loopholes that need to be fixed. The next strategy is further optimization in the form of monitoring the impact of transportation. Projects can implement a fleet of fuel emission tracking systems to quantitatively measure emissions performance. With this strategy, the project can look for additional opportunities to reduce emissions.

b. C2 – Suppliers of Materials and Tools Made in Indonesia

The project has used most structural materials from SNI-certified domestic manufacturers. However, for MEP systems such as elevators and HVAC, projects still rely on imported products due to limited local production capacity. Implementation strategies include expanding Green Procurement requirements for imported items to have energy efficiency certificates, as well as advocacy to the government and industry associations to encourage local producers to develop similar products. Widyaningsih et al. (2022) suggest that strong government regulations can encourage local producers to provide green materials that suit the needs of the project. In the long term, this strategy will help the project meet sustainability targets while supporting the readiness of the domestic industry.

All three projects show commitment to the principles of Green Construction, especially in the reduction of construction waste, efficiency in the use of materials, and the utilization of local supply chains. The entire project has implemented a waste sorting system from source and optimizes materials through technologies such as BIM, steel cutting software, or prefabricated methods. Dharmais Hospital and Harapan Kita Hospital have successfully met the TKDN target according to regulations, reaching 60% and 50%, respectively, while Labtek XV also prioritizes local materials even though they are not required to follow government

regulations. Digital technologies such as 6D BIM, just-in-time implementation, and modular approaches are used throughout projects to support logistics efficiency and material waste reduction.

Notable differences are seen in the level of implementation and scope of green initiatives, which are heavily influenced by certification objectives and project scale. RS Harapan Kita, with the target of LEED Platinum certification, implements the most comprehensive strategy, including carbon offset measures and the use of high-tech materials. Dharmais Hospital, which is targeting Greenship Gold certification, highlights the integration of BIM 6D and the use of environmentally friendly materials. Meanwhile, Labtek XV emphasizes operational efficiency through reuse and modularization, adjusting to the character of education projects that are more limited in terms of budget and regulation. Despite variations in approaches, all three projects have managed to demonstrate a positive contribution to sustainable construction practices, tailoring strategies to the needs, capacities, and challenges of each project.

CONCLUSION

This study found varying levels of Green Construction implementation among three projects: Harapan Kita-Tokushukai Hospital led with 85%, followed by Dharmais Cancer Hospital at 70%, and Labtek XV ITB at 55%. Key barriers included weak regulations, limited access to green materials, absence of national environmental certification, and high costs. Significant gaps were noted in material calculation simulation, waste reporting, and packaging management. Recommended strategies to enhance implementation involve strengthening regulations and incentives, leveraging digital technologies, developing green supply chains, and enhancing human resource capacity, tailored to each project's readiness. Future research should explore the long-term impact of these strategies on project sustainability and investigate scalable models for wider adoption across diverse construction contexts in Indonesia.

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