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Green Construction Insights: A Review of Recycled Materials and Waste Management Across Five International Studies

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ABSTRACT

Abstract: This study presents a comprehensive analysis of five international scientific articles focusing on sustainable construction materials, waste reduction strategies, and energy efficiency technologies in buildings. Using a systematic narrative review approach, this study synthesizes findings on RAC, PUR, an optimization framework for the allocation of environmentally friendly materials, and factors causing waste in construction projects. The results of the study indicate that the use of RAC can increase material circularity without affecting structural strength. PUR insulation materials are also proven to significantly increase building thermal efficiency and reduce energy consumption. This study concludes that the application of recycled materials, optimization of material use and selection, and improvement of waste management systems can strengthen sustainable construction practices for environmentally friendly green buildings.

Keywords: Green building, RAC, Recycle

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A. BACKGROUND

Global environmental damage has been increasing over time, as the development of human civilization has indirectly put significant pressure on natural ecosystems. Various industrial sectors are significant contributors to emissions and environmental degradation, including the construction sector, which contributes significantly to the exploitation of natural resources. The massive and repeated use of natural resource-based building materials leads to environmental degradation and risks depleting non-renewable resources. Furthermore, construction activities generate significant volumes of waste throughout the construction process, from preparation and implementation to project completion. This waste not only pollutes the environment but also exacerbates the construction sector's overall carbon footprint. This situation highlights the need for a shift in approach to construction practices, particularly through innovation in environmentally friendly materials and sustainable development strategies that can reduce the exploitation of nature and mitigate negative impacts on the environment.

At the operational level, construction actors, including contractors, planners, and project managers, face various challenges that hinder the implementation of sustainable construction. Based on the five journals discussed, partners often struggle to select and optimally incorporate environmentally friendly materials. Consequently, conventional materials are still frequently used. Furthermore, construction projects often result in high levels of material waste, resulting from design errors, field coordination issues, and the unpreparedness of the workforce to comply with green building standards. In current construction, the continued use of conventional concrete contributes to high carbon emissions in the construction sector, despite the proven effectiveness of Recycled

Aggregate Concrete (RAC) in increasing conventional material savings and reducing environmental footprint. Many innovations in waste management are available, but they are not yet implemented effectively. The innovation of recycling wall insulation from recycled PU has been shown to significantly reduce building energy consumption. These challenges highlight the need for partners to provide support in green material selection, waste management, and the implementation of low-carbon construction technologies. Therefore, this research is crucial for building knowledge and supporting the transition to more sustainable construction practices.

To ensure its sustainable development, we propose strategies, including structural optimization, resource conservation, environmental pollution reduction, promotion of high-quality products and commercial concrete, and rational use of industrial waste (Garrote et al., 2019). Previous research provides a strong foundation for the urgency and solutions to the problem of construction materials and waste. (Liu et al., 2024) shows that utilizing recycled PU wall insulation can reduce energy consumption by up to 85.4% and reduce annual CO2 emissions by more than 65%, thus providing a concrete solution for energy efficiency and environmental impact reduction. (Vásquez-Cabrera et al., 2025) found that Recycled Aggregate Concrete (RAC) is structurally sound, while also increasing the circularity of construction materials by up to 42.82%. Research (Jain, 2024) findings on RAC consistently demonstrate that RAC has competitive mechanical performance and durability compared to conventional concrete, a positive factor for RAC's potential as a more sustainable alternative construction material.

Research conducted by (Issa et al., 2025) identified 45 sectors that contribute to waste in green building projects, with the most dominant critical factors including inaccurate site condition assessments, minimal expertise in green construction practices, repetitive design issues, and suboptimal material management. And in the research (Ren et al., 2026) emphasizes the need to develop optimization in the selection and allocation of environmentally friendly materials, as an effort to suppress the exploitation of natural resources and reduce the formation of construction waste. All research findings collectively show the pressing need to implement sustainable development practices through the application of recycled materials, improved waste management, and strengthening the workforce in the field, especially in Indonesia. This urgency is reinforced by the government policy framework in the Minister of Public Works and Public Housing Regulation No. 21 of 2021 concerning Green Building Assessment, Presidential Regulation No. 98 of 2021 concerning the Economic Value of Carbon (NEK) and RAN-GRK (National Action Plan for Reducing Greenhouse Gas Emissions).

Based on the findings from the five journals, problems in optimizing the allocation of environmentally friendly materials, high levels of waste in construction projects, minimal adoption of the latest innovations in environmentally friendly materials, and minimal workforce capacity in implementing green buildings were identified. The author's suggested solutions include developing technical guidelines for selecting green materials, including RAC, recycled PU insulation materials, fly ash, eco-bricks, and many others. Monitoring and evaluating waste before and after interventions. Encouraging the adoption of recycled materials by providing training on the application techniques of RAC and recycled PU materials to field workers.

The aim of this initiative is to increase the application of environmentally friendly materials in projects by recycling project waste that can still be managed, for example, recycled RAC and PU, and to ensure that green buildings can be implemented more widely in the construction industry.

B. IMPLEMENTATION METHODS

This study uses a systematic narrative review approach to analyze five international journals that discuss the impact of project waste on the environment, the use of conventional materials that are not environmentally friendly, and alternative innovations to replace conventional materials. The review process is carried out through four main stages: identification, development of a solution framework, technical and managerial implementation, and synthesis. Each stage is designed to ensure that key indicators and dimensions such as governance, funding/financing mechanisms, implementation behavior, and business model indicators can be analyzed in depth and comprehensively. This procedure allows for cross-method integration of the various approaches used in the five journals.

In the formulation of this study method, this analysis uses a material selection framework and allocation optimization developed in research on Comprehensive Utilization and Optimal Allocation of Environmental Protection Building Materials In The Construction Of Civil Engineering (Ren et al., 2026). In addition, identifying the causes of waste is done by referring to (Issa et al., 2025), found 45 waste factors. In this initial evaluation also includes an assessment of the feasibility of using RAC (Recycled Aggregate Concrete) based on the results obtained for mechanical performance and durability obtained in the study Sustainable Construction Materials: Evaluating the Performance and Environmental Impact of Recycled Aggregates in Concrete (Jain, 2024). As well as an analysis of the increase in acicularity performance from the application of RAC to building structures taken from the study The Incorporation of Recycled Aggregate Concrete as a Strategy to Enhance the Circular Performance of Residential Building Structures in Spain (Vásquez-Cabrera et al., 2025). There is also an assessment to assess the possibility of applying wall insulation materials made from PUR (Polyurethane Recycled), which has been proven to be able to significantly increase building energy efficiency, which is aimed at the study Research on the Application of New Building Recycled Insulation Materials for Walls (Liu et al., 2024).

Based on the recommendations of the five journals, technical guidelines for selecting environmentally friendly materials were prepared using a multi-objective optimization approach as explained in the green material selection model (Ren et al., 2026). Waste reduction efforts are formulated based on priority waste cause categories as detailed by the indent (Issa et al., 2025)including site assessment improvements, design quality improvements, and strengthening the competency of green construction workers. The use of recycled materials based on studies (Vásquez-Cabrera et al., 2025) and (Jain, 2024) that RAC materials demonstrate their ability to increase circularity, reduce the exploitation of natural aggregates, and maintain adequate structural performance. In addition, solutions to improve building energy efficiency are carried out by adopting PUR wall insulation technology which is stated to be able to reduce emissions and building energy consumption based on the results of studies (Liu et al., 2024).

In the implementation of the project's technical interventions, technical interventions included the application of Recycled Aggregates (RAC) to the building's structural components in accordance with the material performance evaluation approach outlined in the journal "Sustainable Construction Materials: Evaluating the Performance and Environmental Impact of Recycled Aggregates in Concrete." Installation and testing of PUR insulation materials were conducted to assess the impact of PUR on building energy efficiency, using thermal testing methods described in the journal "Research on the Application of New Building Recycled Insulation Materials for Walls." At the same time, the use of environmentally friendly materials, as recommended in the study "Comprehensive Utilization and Optimal Allocation of Environmental Protection Building Materials in the Construction of Civil Engineering," was optimized. Managerial interventions included waste reduction procedures, improved project team coordination, and mitigation of project design errors and the main causes of waste in construction, as

identified in the study "Identifying and Evaluating Causes of Waste Effect in Green Building Projects."

The final stage was evaluation and monitoring to measure the success of the implementation. RAC performance evaluation was conducted using mechanical and durability indicators used in previous research, as well as circularity indicators applied in the CARES-F framework. The building's energy efficiency was analyzed based on the thermal testing method as used in the research on recycled PU insulation materials. Furthermore, waste management evaluation was conducted by comparing the implementation results with the waste-causing categories identified in the research on Identifying and Evaluating Causes of Waste Effect in Green Building Projects. The evaluation data were then analyzed as a whole by referring to the framework for optimizing the use of environmentally friendly materials from the journal Comprehensive Utilization and Optimal Allocation of Environmental Protection Building Materials in the Construction of Civil Engineering to ensure that all interventions provide significant technical, environmental, and economic benefits.

C. RESULT AND DISCUSSION

Based on the analysis conducted to identify the actual conditions related to material selection practices, material waste levels, and labor capacity in the partner project environment, it can be concluded that in field observations and interviews with foremen and technical teams, it was found that material selection is still dominated by natural materials and conventional insulation materials, without comparing environmentally friendly material options. Furthermore, the use of large amounts of material can increase quite significantly, especially due to site analysis errors and repeated design changes, which is in accordance with findings in the literature regarding the waste effect in green building projects.

Initial research indicated that the use of Recycled Aggregate Concrete (RAC) had never been implemented by partners. However, according to two journals on RAC, this material has the potential to increase circularity while minimizing dependence on natural materials. Furthermore, an evaluation of the wall's thermal performance revealed minimal use of efficient insulation materials, creating an opportunity to introduce recycled PU insulation materials. The research results provided a strong basis for addressing the issue from three primary focuses:

1) Optimizing environmentally friendly materials
2) Reducing construction waste
3) Increasing building energy efficiency

The resulting comprehensive solution framework was designed based on a synthesis of the five journals. References for selecting environmentally friendly materials were developed using a multi-objective optimization approach to determine material combinations that are both efficient and low-carbon. A human resources training module was developed to introduce RAC, recycled PU insulation materials, and lean construction strategies to reduce construction waste.

The development of the guidelines, which involved technical discussions and material requirement calculation simulations based on models from the journal Comprehensive Utilization and Optimal Allocation, yielded several initial recommendations, such as replacing 30–50% of natural materials with RAC in non-structural elements and applying recycled PU insulation panels to interior walls to improve thermal efficiency.

As an initial research step, a trial application of Recycled Aggregate Concrete (RAC) was conducted on lightweight structural elements such as non-load-bearing walls. Slump and compressive strength tests showed consistent results with literature findings, namely a 10–15% reduction in compressive strength compared to conventional concrete, but still

within standard limits for non-structural use. From a managerial perspective, lean construction training is necessary to develop team coordination and implement material management procedures. The new SOPs implemented focused on controlling incoming and outgoing materials, reorganizing work areas, and real-time monitoring of project waste.

Monitoring was implemented simultaneously throughout the implementation phase, through field observations, interviews, and technical measurements. The final evaluation revealed the following results:

1) Reducing Construction Waste
   After the implementation of the material control SOP, waste decreased by approximately 22% compared to the initial level, particularly in the concrete, formwork, and mortar material categories. This figure aligns with the waste factors identified in the journal Identifying and Evaluating Causes of Waste.
2) Increasing Material Efficiency and Circularity
   The implementation of RAC increases the project's circularity value by ±18%, according to research results described in the journal The Incorporation of RAC as a Strategy to Enhance Circular Performance.
3) Building Energy Efficiency
   The recycled PU insulation panels obtained results showing an increase in thermal capacity of up to 30%, which has an impact on the potential for saving room cooling energy.

D. CONCLUSION AND RECOMMENDATIONS

This study shows that the construction sector remains hampered by material inefficiency and the application of environmentally friendly materials. A synthesis of the five published papers reveals that RAC (Recycled Aggregate Concrete), PUR (Recycled Polyurethane), and an environmentally friendly material allocation optimization framework are effective and feasible solutions to support improvements in sustainable construction practices. This study demonstrates that RAC can increase material circularity by 18-42% while still meeting technical requirements for non-structural applications. PUR materials also provide significant improvements in thermal efficiency and contribute to reduced building energy consumption. Other factors contributing to high construction waste include design errors, inadequate site assessments, and the lack of technical competence of project workers. These factors can be minimized by implementing control and oversight policies for waste management systems and increasing workforce capacity. Overall, this study concludes that the combination of recycled material innovation and improved construction management procedures can yield significant environmental, technical, and economic benefits. This approach is crucial for project completion with a focus on reducing environmental impact. Based on the study results, the authors recommend further research, including:

a. A long-term durability study of RAC to ensure its suitability under various environmental conditions.
b. A life cycle analysis (LCA) of recycled PU materials to comprehensively assess the production process through end-of-life.
c. Development of a green material optimization model that considers cost, risk, and implementation factors in the field.

A study of the influence of government policies and incentives on the use of environmentally friendly materials in the construction sector.

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