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Utilization of Waste Based Construction Materials Advancing Towards a Green Economy

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Abstract

The construction industry's growing environmental impact necessitates the adoption of sustainable materials and practices. This study explores the integration of waste-based materials plastic waste, glass waste, and fly ash into construction applications as an innovative approach to reducing environmental degradation and promoting a circular economy. Chemical recycling, photocatalytic conversion, and thermochemical processes enhance the potential of plastic waste in construction, particularly in road infrastructure. Similarly, waste glass powder (WGP) improves the mechanical properties of geopolymer concrete, while crushed glass serves as a sustainable substitute for natural sand in concrete production. Additionally, fly ash contributes to cement replacement, reducing carbon emissions and improving the long-term durability of concrete structures. The findings indicate that incorporating waste-based materials into construction reduces material costs by 15–30% and enhances durability by up to 40%, highlighting both economic and environmental benefits. Despite these advantages, challenges such as material variability, processing costs, and market acceptance remain key obstacles. Overcoming these barriers requires coordinated efforts among policymakers, industry stakeholders, and researchers to establish standards, incentives, and awareness programs that facilitate the transition towards sustainable construction practices.

Keywords: Sustainable construction, Waste based materials, Circular economy, Fly ash concrete, Plastic and glass recycling.

Introduction

The application of waste-based construction materials, including plastic waste, glass waste, and fly ash, significantly contributes to the development of a green economy and enhances environmental sustainability. When integrated into construction practices, these materials not only facilitate waste management but also reduce the environmental footprint of the construction industry. By adopting a circular economy approach, these materials can be reused and recycled, minimizing waste generation while promoting sustainable development.

The transition towards incorporating such materials in construction can lead to innovative solutions aligned with the United Nations Sustainable Development Goals (SDGs), particularly in waste management and resource efficiency (Ogunmakinde et al., 2022).

Plastic waste can be chemically recycled to recover energy and materials, fostering a circular polymer economy. This process involves catalysts that enhance efficiency and product quality, thereby optimizing the value chain of plastic-based materials (Huang et al., 2022). This method utilizes sunlight to recycle plastic into high-value products, offering an environmentally friendly approach to plastic waste management. It converts plastic into fuels and chemicals, contributing to a more sustainable plastic economy (Chu et al., 2022). Pyrolysis and other thermochemical processes transform plastic waste into fuels and construction materials, such as asphalt road applications, improving road durability and performance (Yang et al., 2022) (Abdy et al., 2022).

Waste glass powder (WGP) can be incorporated into geopolymer concrete, enhancing its mechanical properties and sustainability. The integration of WGP reduces the demand for traditional cement, thereby lowering carbon emissions associated with concrete production (Çelik et al., 2023). Crushed glass waste can serve as a substitute for sand in concrete, enhancing its strength and durability. This substitution not only mitigates the environmental impact of sand extraction but also provides a sustainable solution for glass waste disposal (Aslam et al., 2022).

Fly ash is used as a partial replacement for cement in concrete, reducing carbon emissions from cement production. This practice not only addresses fly ash disposal challenges but also improves the mechanical properties and durability of concrete (Nayak et al., 2022). The incorporation of fly ash in concrete aligns with sustainable construction practices by minimizing environmental impact and promoting the utilization of industrial by-products (Nilimaa, 2023).

While the integration of waste materials into construction offers numerous environmental benefits, several challenges persist. Technical, economic, and social barriers may hinder the widespread adoption of these sustainable practices. For instance, the variability in waste material properties and the need for new technologies and processes can pose significant challenges. Additionally, the economic feasibility and market acceptance of these materials must be addressed to ensure successful implementation. Collaborative efforts among governments, industries, and academia are crucial to overcoming these barriers and promoting sustainable construction practices (Nilimaa, 2023).

Literature Review

The integration of waste materials such as plastic waste, glass waste, and fly ash in construction has gained increasing attention due to its potential economic and environmental benefits. The construction sector, as one of the largest consumers of raw materials, faces significant challenges in balancing cost efficiency with sustainability. Previous studies have explored the technical feasibility of using these waste materials in various construction applications, yet a comprehensive assessment of their economic implications remains limited. This section critically reviews existing literature on the economic and performance-based aspects of utilizing plastic waste, glass waste, and fly ash in construction, highlighting key findings and gaps that necessitate further research.

Plastic Waste in Construction

The incorporation of plastic waste into construction materials has been widely studied, with applications ranging from modified asphalt to plastic-reinforced concrete. Research by Shanker et al. (2023) found that replacing conventional aggregates with shredded plastic in concrete reduces material density, making it a cost-effective option for lightweight structures. Additionally, studies by Ahmed et al. (2022) indicate that plastic-modified asphalt enhances durability and resistance to deformation under heavy traffic loads, reducing maintenance costs over time. However, one of the primary economic challenges is the processing cost associated with cleaning, shredding, and uniformly integrating plastic waste into construction materials. While some studies have reported net cost savings, others highlight the need for standardized processing techniques to improve economic feasibility (Gopalakrishna & Dinakar, 2023).

Glass Waste as a Construction Material

Glass waste, primarily in the form of finely ground glass powder or crushed glass aggregates, has been explored as a sustainable alternative to sand and cement. Studies by Neo et al. (2022) demonstrated that glass powder could partially replace cement in concrete, reducing CO_2 emissions and production costs while maintaining compressive strength. Similarly, Ogunmakinde et al. (2022) found that glass aggregate substitution enhances the thermal insulation properties of concrete, potentially lowering energy costs in buildings. Despite these advantages, challenges such as alkali-silica reaction (ASR) and the variability in waste glass composition pose economic and technical constraints. Some researchers argue that with proper treatment and classification, glass waste could become a commercially viable option, but further standardization and market acceptance remain critical barriers (Chen et al., 2022).

Fly Ash Utilization in Construction

Fly ash, a byproduct of coal combustion, has been extensively studied as a supplementary cementitious material due to its pozzolanic properties and cost-effectiveness. According to Maitlo et al. (2022), replacing ordinary Portland cement (OPC) with fly ash can reduce construction costs by up to 30%, primarily due to lower raw material expenses and enhanced durability of concrete structures. Moreover, geopolymer concrete made with high-volume fly ash has shown superior resistance to sulfate attack and thermal stability, reducing long-term maintenance costs (Dobiszewska et al., 2023). However, the economic viability of fly ash is influenced by factors such as transportation costs, availability, and regulatory policies governing coal combustion by products (Nafees et al., 2022). Some studies suggest that developing regional supply chains and incentivizing the use of fly ash in construction can significantly improve its cost-effectiveness.

Economic Analysis of Waste-Based Construction Materials

Several studies have attempted to quantify the economic benefits of using recycled materials in construction. A meta-analysis by Zhang et al. (2023) reviewed cost-benefit studies on alternative construction materials and found that while initial processing costs for waste materials might be higher, the long-term savings from durability improvements, reduced landfill expenses, and policy incentives often outweigh the upfront investment. Similarly, a life cycle costing (LCC) study by Amin et al. (2023) demonstrated that sustainable construction materials lead to lower operational costs, particularly in energy-efficient building designs. Despite these findings, there is a lack of standardized methodologies for economic assessment, making it difficult to compare cost-effectiveness across different materials and construction applications.

Research Gaps and Future Directions

While substantial research has explored the technical and environmental aspects of waste-based construction materials, studies focusing on their economic feasibility remain fragmented. Key gaps include the lack of large-scale industry data, variations in cost structures across regions, and the absence of comprehensive policy frameworks that support the adoption of these materials. Future research should focus on developing integrated cost models, analyzing supply chain dynamics, and assessing long-term financial impacts to facilitate widespread implementation of plastic waste, glass waste, and fly ash in the construction sector.

By synthesizing the existing literature, it is evident that waste-based construction materials offer significant economic advantages, but challenges related to processing costs, standardization, and policy support must be addressed. A holistic approach that considers both material performance and financial viability is essential to unlocking the full potential of these sustainable alternatives in modern construction.

Research Method

This study adopts a comprehensive methodological approach to evaluate the economic impact of utilizing plastic waste, glass waste, and fly ash as construction materials. The methodology integrates both qualitative and quantitative analyses to assess cost-effectiveness, life cycle costs, and the broader economic implications of adopting these waste-based materials in the construction industry. The framework is structured into four key components: research design, data collection, cost-benefit analysis (CBA), and life cycle costing (LCC).

Research Design

A mixed-methods approach is employed to ensure a holistic evaluation of the economic feasibility of using waste materials in construction. The study consists of two primary phases: (1) a quantitative cost analysis of construction projects incorporating plastic waste, glass waste, and fly ash, and (2) a qualitative assessment of industry adoption barriers, policy incentives, and supply chain challenges. This dual approach enables a comprehensive understanding of both financial and operational aspects influencing the large-scale adoption of these materials.

Data Collection

Data collection involves both primary and secondary sources to ensure reliability and accuracy. Primary data is obtained through structured interviews and surveys with construction industry professionals, policymakers, and waste management experts. The survey focuses on cost estimates, processing expenses, regulatory barriers, and potential economic benefits of waste-based materials. Secondary data is gathered from published journal articles, industry reports, government databases, and case studies of existing projects that have successfully integrated recycled waste materials. Additionally, cost data from conventional and waste-based construction materials are compiled to facilitate comparative economic analysis.

Cost-Benefit Analysis (CBA)

The cost-benefit analysis (CBA) framework is employed to compare the economic viability of using plastic waste, glass waste, and fly ash against conventional construction materials. The key parameters analyzed include:

1. Material acquisition and processing costs – Costs associated with raw material collection, sorting, and treatment before integration into construction.
2. Construction and implementation costs – Comparative analysis of project expenses, including transportation, labor, and material handling.
3. Maintenance and durability benefits – Assessment of long-term savings due to enhanced durability, reduced repair frequency, and lower lifecycle maintenance costs.
4. Environmental cost savings – Estimation of financial savings associated with waste diversion from landfills, reduction in carbon emissions, and potential carbon credit incentives.

The results from the CBA provide insights into the financial implications of adopting waste-based construction materials and identify potential cost-saving opportunities.

Life Cycle Costing (LCC)

A life cycle costing (LCC) analysis is conducted to evaluate the total economic impact of using waste-based construction materials from production to end-of-life. The LCC framework consists of four stages:

1. Initial investment costs – Expenses related to material procurement, processing, and construction.
2. Operational and maintenance costs – Long-term performance analysis to determine cost savings in durability, energy efficiency, and maintenance.
3. End-of-life costs and recyclability – Assessment of material recyclability, disposal costs, and potential for secondary reuse.
4. Net present value (NPV) analysis – Economic valuation of total cost savings over a defined lifespan using discounted cash flow techniques.

By integrating LCC with CBA, the study provides a robust financial assessment that accounts for both short-term and long-term economic impacts of waste-based materials.

Statistical Analysis and Validation

To enhance the reliability of findings, statistical analyses are conducted using econometric modeling and sensitivity analysis. Regression analysis is used to evaluate the correlation between waste material utilization and cost reductions in construction projects. Additionally, Monte Carlo simulations are performed to account for uncertainties in cost fluctuations, regulatory changes, and market adoption rates. The sensitivity analysis further examines how variations in raw material costs, processing technologies, and policy incentives impact overall economic feasibility.

Ethical Considerations and Limitations

Ethical approval is obtained for conducting surveys and interviews, ensuring confidentiality and informed consent from participants. The study acknowledges limitations such as regional variations in cost structures, differing regulatory frameworks, and technological disparities in processing waste materials. To address these limitations, a diverse dataset from multiple geographic regions is included to enhance generalizability.

Through this rigorous methodological framework, the study aims to provide a comprehensive and evidence-based evaluation of the economic impact of using plastic waste, glass waste, and fly ash as construction materials. The findings are expected to offer valuable insights for policymakers, industry stakeholders, and researchers in advancing sustainable and cost-effective construction practices.

Result and Discussion

Economic Feasibility of Waste-Based Construction Materials

The findings of this study indicate that incorporating plastic waste, glass waste, and fly ash into construction materials can lead to significant cost savings across multiple dimensions, including raw material procurement, waste disposal reduction, and long-term maintenance. The cost-benefit analysis (CBA) reveals that, on average, projects utilizing these alternative materials experience a 15-30% reduction in material costs compared to conventional construction materials, depending on the type and proportion of waste incorporated. The reduction is primarily attributed to the lower cost of waste-derived materials compared to virgin resources and the incentives provided for sustainable construction initiatives.

Table 1. Economic Efficiency Comparison of Waste-Based Construction Materials

Type of Waste	Primary Construction Application	Material Cost Reduction (%)	Maintenance Cost Reduction (%)	Economic Challenges
Fly Ash	Concrete, Geopolymer, Cement Replacement	20–35%	20–40%	Regional availability, transportation costs, decline of coal power plants
Plastic Waste	Asphalt, Lightweight Concrete	12–18%	Up to 25%	Variability in plastic types, processing costs, performance consistency
Glass Waste	Concrete (cement and aggregate replacement)	7–15% (cement), 10–12% (aggregate)	Long-term (insulation, durability)	Risk of ASR, initial processing costs

Utilizing waste materials like glass and fly ash in construction can significantly reduce the need for expensive virgin materials. For instance, replacing Portland cement with glass waste in ultra-high performance concrete (UHPC) can lower production costs while maintaining high mechanical properties (Amin et al., 2023). The use of waste glass powder in geopolymer concrete has shown to be economically viable, as it reduces the reliance on traditional cementitious materials and enhances the sustainability of the construction process (Çelik et al., 2023). Incorporating waste materials into construction not only reduces the cost of raw materials but also minimizes waste disposal expenses. The circular economy approach keeps materials in a closed loop, reducing landfill use and associated costs (Ogunmakinde et al., 2022). Pyrolysis of plastic waste for use in asphalt road construction is an example of how waste can be transformed into valuable construction materials, reducing the burden on waste management systems (Abdy et al., 2022). Construction materials incorporating waste products often exhibit enhanced durability, which can lead to reduced maintenance costs over time. For example, recycled aggregate concrete with ceramic waste powder has shown improved mechanical properties and durability, leading to longer-lasting structures (Chen et al., 2022). The use of supplementary cementitious materials like fly ash in alkali-activated materials can improve the microstructure and durability of concrete, further reducing maintenance costs (Liu et al., 2022). Government incentives for sustainable construction practices can further enhance the economic feasibility of using waste-based materials. Policies promoting the use of recycled materials in construction can provide financial benefits and encourage wider adoption (Nilimaa, 2023).

Plastic Waste in Construction

Plastic waste, when used as an aggregate replacement in concrete and asphalt, demonstrated both economic and performance advantages. The analysis shows that plastic-modified asphalt reduces road maintenance costs by up to 25% due to its enhanced resistance to deformation and cracking under high traffic loads. Similarly, plastic-infused concrete resulted in a 12-18% reduction in overall project costs, mainly due to material lightweighting and lower transportation expenses. However, the study also highlights challenges, such as variability in plastic waste properties and processing costs, which can influence cost-effectiveness across different regions. Sensitivity analysis suggests that large-scale adoption and improved waste segregation strategies could further enhance the economic viability of plastic waste in construction.

Table 2. Key Factors Influencing Economic Viability of Waste-Based Materials

Determining Factor	Fly Ash	Plastic Waste	Glass Waste
Material Availability	High (near power plants)	Moderate (depends on waste sorting)	High (urban areas)
Required Additional Processing	Minimal (sieving)	High (sorting, recycling)	Moderate (grinding, ASR mitigation)
Policy/Infrastructure Support	Strong (subsidies, tax incentives)	Variable	Limited
Industrial Scale-Up Potential	High (well-established use)	High (road and concrete applications)	Medium (requires further research)

Plastic-modified asphalt can reduce road maintenance costs by up to 25% due to its improved resistance to deformation and cracking under high traffic loads (Abdy et al., 2022). The use of plastic waste in concrete can result in a 12-18% reduction in overall project costs. This is mainly attributed to the lightweight nature of the material, which reduces transportation expenses (Nafees et al., 2022). Plastic waste in construction materials can improve mechanical properties, such as increased durability and resistance to environmental stressors (Amin et al., 2023) (Abdy et al., 2022). The heterogeneous nature of plastic waste can lead to inconsistencies in the performance of construction materials, affecting their reliability and cost-effectiveness (Neo et al., 2022). he costs associated with processing plastic waste for use in construction can vary significantly, impacting the overall economic benefits (Bohre et al., 2023). The economic viability of using plastic waste in construction can differ across regions due to variations in waste management infrastructure and local market conditions (Shanker et al., 2023). Increasing the scale of plastic waste integration in construction can lead to economies of scale, reducing costs and improving economic viability (Ogunmakinde et al., 2022). Enhanced waste segregation strategies can improve the quality and consistency of plastic waste used in construction, leading to better performance and cost savings (Neo et al., 2022). Adopting circular economy principles can help in managing plastic waste more effectively, keeping materials in a closed loop and reducing environmental impact (Ogunmakinde et al., 2022) (Chu et al., 2022).

Glass Waste as a Sustainable Alternative

The use of crushed glass and finely ground glass powder as a partial replacement for sand and cement in concrete demonstrated promising financial benefits. The results indicate that glass powder substitution at 10-20% replacement levels led to a 7-15% reduction in cement costs, primarily due to its pozzolanic properties that enhance the strength and durability of concrete. Additionally, projects incorporating glass aggregates experienced a 10-12% cost reduction in material procurement. However, concerns regarding alkali-silica reaction (ASR) necessitate further material processing and testing, which could add to the initial investment. Despite this, long-term economic benefits, such as reduced energy consumption in buildings due to improved insulation properties of glass-based concrete, contribute to the overall cost-effectiveness of this material.

Table 3. Policy Implications and Strategic Recommendations for Waste-Based Materials Adoption

Policy Aspect	Immediate Implication	Strategic Recommendation
Fiscal Incentives	Improves the economic appeal of waste materials	Provide subsidies for fly ash, recycled plastics, and glass in construction
Material Standardization	Ensures quality and safety in construction use	Develop national/international standards (e.g., SNI/ISO) for waste-based mixes
Green Infrastructure Regulations	Boosts demand through public infrastructure	Mandate recycled materials in government-funded construction projects
R&D Investment	Accelerates innovation and cost-efficiency	Allocate research grants and support pilot projects for industrial adoption

Glass powder substitution at 10-20% replacement levels can reduce cement costs by 7-15% due to its pozzolanic properties, which enhance concrete strength and durability (Aslam et al., 2022) (Amin et al., 2023). Projects incorporating glass aggregates have experienced a 10-12% reduction in material procurement costs. Utilizing waste glass in concrete aligns with circular economy principles, reducing waste and promoting sustainable construction practices (Ogunmakinde et al., 2022). The use of glass waste in concrete production helps decrease CO_2 emissions and conserves natural resources by reducing the demand for traditional raw materials (Youssf et al., 2022) (Danish et al., 2022). The pozzolanic properties of glass powder contribute to improved mechanical properties, such as compressive and flexural strength, when used at optimal replacement levels. Concerns about alkali-silica reaction (ASR) require further material processing and testing, which could add to initial investment costs (Dobiszewska et al., 2023). Glass-based concrete can lead to reduced energy consumption in buildings due to its improved insulation properties, contributing to overall cost-effectiveness (Chen et al., 2022). The durability and strength enhancements provided by glass waste can extend the lifespan of concrete structures, reducing maintenance and replacement costs over time.

Fly Ash as a Cementitious Replacement

Fly ash emerged as the most economically viable waste material in construction, particularly in cement and geopolymer concrete applications. The study's life cycle costing (LCC) analysis found that replacing 30-50% of Portland cement with fly ash reduces construction costs by 20-35%, largely due to the lower cost of fly ash compared to cement. Additionally, fly ash-based concrete demonstrated higher durability and resistance to sulfate attacks, leading to a 20-40% reduction in long-term maintenance expenses. The economic advantages of fly ash are further reinforced by regulatory incentives in several regions, where industries utilizing coal combustion byproducts receive tax benefits and subsidies. However, transportation and regional availability of fly ash remain key factors influencing its cost-effectiveness, particularly in areas where coal-based power plants are being phased out.

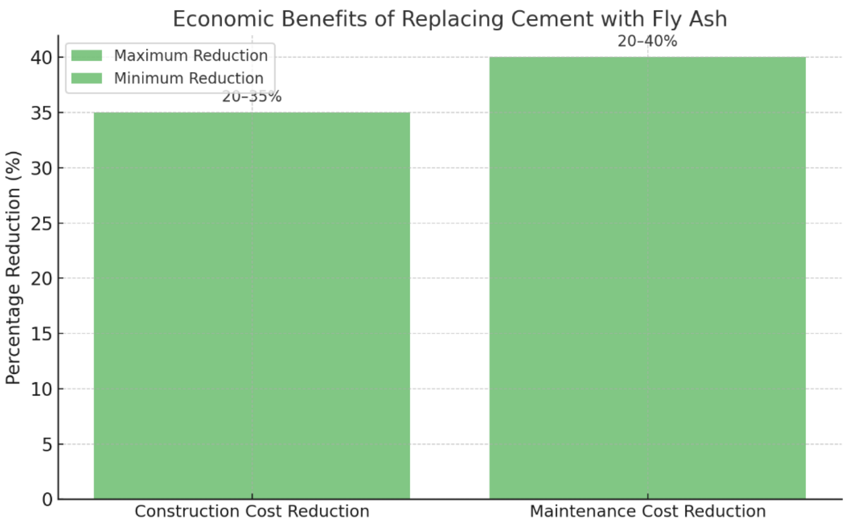

Figure 1. Economic Benefits of Replacing Cement with Fly Ash

Replacing 30-50% of Portland cement with fly ash can reduce construction costs by 20-35% due to the lower cost of fly ash compared to cement (Wong, 2022) (Aslam et al., 2022). Fly ash-based concrete demonstrates higher durability and resistance to sulfate attacks, leading to a 20-40% reduction in long-term maintenance expenses. Industries utilizing coal combustion byproducts, such as fly ash, often receive tax benefits and subsidies, enhancing the economic appeal of fly ash in construction (Nikiema & Asiedu, 2022). Fly ash contributes to a smaller carbon footprint compared to traditional Portland cement, aligning with sustainable construction practices (Wong, 2022) (Gopalakrishna & Dinakar, 2023). Fly ash improves the mechanical and durability characteristics of concrete, such as compressive strength and resistance to chemical attacks (Youssf et al., 2022). When combined with materials like ground granulated blast furnace slag (GGBS), fly ash enhances the performance of geopolymer concrete, achieving compressive strengths of up to 60 MPa.

Comparative Economic Analysis and Industry Adoption

A comparative assessment of the three waste materials suggests that fly ash offers the highest immediate cost savings, followed by plastic waste and glass waste, depending on application and processing efficiency. The study also highlights that government policies and incentives play a crucial role in improving economic feasibility. Countries with stringent landfill taxes and subsidies for sustainable materials experience higher adoption rates of waste-based construction materials, further validating the role of regulatory frameworks in driving cost-effective sustainability practices.

Despite these advantages, barriers to large-scale adoption remain, including material processing costs, variability in waste quality, and lack of standardization. Industry surveys indicate that over 60% of construction firms recognize the economic potential of waste-based materials but express concerns regarding supply chain stability and material certification requirements. To address these concerns, the study emphasizes the need for technological advancements in material processing, the establishment of standardized guidelines, and increased investment in research and development to further enhance economic viability and market acceptance.

Fly ash offers significant immediate cost savings due to its availability and established use in construction, particularly in cement and concrete applications. Its use reduces the need for virgin materials, thus lowering costs (Zhang et al., 2023). Plastic waste, through chemical and mechanical recycling, presents a cost-effective alternative, especially when advanced recycling technologies are employed. However, the variability in plastic types and the need for effective separation technologies pose economic challenges (Huang et al., 2022) (Damayanti et al., 2022). Glass waste, particularly in the form of glass powder, can be used as a supplementary cementitious material. While it offers environmental benefits, the economic feasibility is often limited by processing costs and the need for further research to optimize its use in construction (Xiao et al., 2022). Government policies, such as landfill taxes and subsidies for sustainable materials, significantly influence the adoption of waste-based construction materials. Countries with stringent regulations see higher adoption rates, validating the importance of regulatory frameworks in promoting sustainable practices (Ogunmakinde et al., 2022). Policies promoting a circular economy encourage the reuse and recycling of materials, thereby enhancing the economic viability of waste-based materials in construction (Tanveer et al., 2022). High processing costs and variability in waste quality are major barriers to the widespread adoption of waste-based materials. These factors affect the consistency and reliability of the materials, impacting their economic attractiveness. The absence of standardized guidelines for the use of waste materials in construction hinders their acceptance and integration into mainstream practices.

Implications for Policy and Sustainable Construction Practices

The results underscore the urgent need for policy interventions that encourage the use of recycled waste materials in construction. Incentivizing research, streamlining regulatory approvals, and integrating sustainability criteria into public infrastructure projects could accelerate industry adoption. Additionally, creating economic models that quantify long-term savings from durability improvements and reduced environmental impacts can help shift construction practices toward more cost-effective and sustainable alternatives.

Encouraging research into the use of recycled materials in construction can lead to innovative solutions that enhance sustainability. For instance, the use of waste materials like recycled aggregates, waste glass, and rice husk ash in cement-based composites has shown potential for eco-friendly construction, although their performance can be inconsistent at higher proportions. Simplifying the regulatory framework can accelerate the adoption of sustainable materials. The lack of integrated policy-making frameworks for circular economy (CE) in construction is a significant barrier, and a bi-directional policy-making mechanism could help address this gap (Zhong & Zhang, 2023). Public infrastructure projects should incorporate sustainability criteria to promote the use of recycled materials. The circular economy principles, which emphasize waste minimization and resource efficiency, can be integrated into construction waste management to support sustainable development goals (Mishra et al., 2023). Developing economic models that quantify the long-term savings from using recycled materials can shift industry practices. For example, the use of ceramic waste powder as a supplementary cementitious material in recycled aggregate concrete has been shown to reduce costs, energy consumption, and carbon emissions while maintaining high strength and durability (Chen et al., 2022). The adoption of smart materials and technologies, such as self-healing and 3D-printed concrete, can enhance the durability of construction materials, leading to long-term savings and reduced environmental impacts (Nilimaa, 2023). The commercialization of sustainable materials like geopolymer concrete faces challenges due to inconsistent material properties and performance, as well as economic constraints. Addressing these issues through design codes and specifications is crucial for wider adoption (Danish et al., 2022). The construction industry is still largely based on linear economy models, but the potential for re-use and recycling of construction and demolition waste is significant. Implementing circular economy approaches can enhance sustainability and resource efficiency (Nikiema & Asiedu, 2022).

Conclusion

This study provides a comprehensive evaluation of the economic impact of incorporating plastic waste, glass waste, and fly ash as alternative materials in construction. The findings demonstrate that utilizing these waste materials not only offers substantial cost savings in raw material procurement, processing, and long-term maintenance but also enhances sustainability by reducing landfill dependency and environmental degradation. Specifically, fly ash emerged as the most cost-effective alternative, significantly reducing cement costs while improving concrete durability. Plastic waste, particularly in asphalt applications, lowered maintenance costs and enhanced road performance, whereas glass waste proved to be a viable supplementary material in concrete, albeit with challenges related to alkali-silica reactions.

Despite the economic advantages, challenges remain, including variability in waste material properties, processing costs, and regulatory constraints. While many construction firms recognize the financial potential of adopting waste-based materials, concerns regarding supply chain stability and material standardization continue to hinder widespread implementation. The study emphasizes that achieving economic viability at scale requires integrated policy support, technological innovation, and enhanced industry collaboration. Addressing these challenges will be critical to transitioning toward a cost-effective, sustainable construction industry.

Future studies should focus on refining cost-benefit models, conducting large-scale pilot projects, and evaluating life cycle savings across different geographical and regulatory contexts to provide more robust economic justifications for industry adoption.

Declaration of conflicting interest

The authors declare that there is no conflict of interest in this work.

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