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Circular Economy R Framework and Sustainability of Construction Industry in Kenya

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Abstract: ***The construction industry is one of the largest consumers of natural resources and a major contributor to construction and demolition waste, posing significant environmental, economic, and social sustainability challenges. The Circular Economy (CE) R Framework, comprising Reduce, Reuse, Recycle, and Redesign, has emerged as a promising approach for improving resource efficiency and promoting sustainable construction. However, empirical evidence on its effectiveness in developing countries, particularly Kenya, remains limited. This study examined the influence of the Circular Economy R Framework on sustainability in Kenya's construction industry. The study employed a quantitative cross-sectional correlational research design. Data were collected from 81 construction professionals drawn from registered firms within the Nairobi Metropolitan region using a structured questionnaire. Pearson correlation and multiple linear regression analyses were performed using SPSS version 26 to examine the relationships between the Circular Economy practices and sustainability. The findings revealed that all four Circular Economy practices had positive and statistically significant relationships with sustainability. Reuse exhibited the strongest correlation with sustainability ($r = 0.873$, $p < 0.001$), followed by Reduce ($r = 0.861$), Recycle ($r = 0.819$), and Redesign ($r = 0.794$). Multiple regression analysis showed that the Circular Economy R Framework collectively explained 87.5% of the variation in sustainability ($R^2 = 0.875$, $F = 132.812$, $p < 0.001$). Among the predictors, Reuse ($\beta = 0.329$) and Redesign ($\beta = 0.307$) exerted the strongest positive effects on sustainability. The study concludes that the integrated implementation of the Circular Economy R Framework significantly enhances sustainability within the construction industry. It recommends that policymakers strengthen regulatory frameworks supporting circular construction, while construction firms invest in material reuse, sustainable design, waste reduction, and recycling systems to improve environmental performance and resource efficiency. The findings contribute to the growing body of knowledge on circular economy implementation and provide practical insights for advancing sustainable construction in developing economies.***

Keywords: Circular economy, sustainability, construction industry, reduce, reuse, recycle, redesign, Kenya.

1. Introduction

The construction sector is the largest consumer of raw materials and resources globally (Ellen MacArthur Foundation [EMF], 2020). With the United Nations projecting that the world population will reach approximately 9.7 billion by 2050, the demand for resources is expected to increase significantly (United Nations, 2019). This population growth will lead to a corresponding rise in the consumption of raw materials, which is estimated to reach 90 billion tons annually by 2050 (Schandl et al., 2016). On a global scale, the construction industry generates approximately 2.2 billion tons of waste annually, of which only 40% is reused, recycled, or sent to waste-to-energy facilities, while the remaining 60% is sent to landfills (Guerra et al., 2021). This alarming trend has raised concerns about the sustainability of the built environment and has prompted stakeholders in the construction industry to rethink their supply chains. The goal is to adopt innovative, environmentally conscious approaches that minimize the negative impact of construction activities. One such approach is the R framework under the umbrella of the circular economy (CE) paradigm.

The circular economy (CE) is an emerging alternative to the traditional linear model of "make-use-dispose." Unlike the linear model, which treats materials as disposable after use, the CE focuses on closing the loop by minimizing waste and maximizing resource efficiency. The CE is built on three fundamental principles: reduce, reuse, and recycle. Its overarching objective is to minimize the use of virgin resources and promote sustainable development (Al Sholi et al., 2023). Research has demonstrated that the CE, particularly through the 4Rs framework (reduce, reuse, recycle, and redesign), can significantly reduce the carbon footprint associated with the production of new materials. As a result, the CE is not only a pathway to environmental sustainability but also a driver of economic sustainability.

According to Geissdoerfer et al. (2017), the CE is a regenerative system that minimizes resource input, waste emissions, and energy leakage by slowing, closing, and narrowing material and energy loops. This is achieved through strategies such as long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling. In essence, the CE aims to decouple economic growth from resource extraction and maximize resource efficiency through the R frameworks.

The CE is governed by a set of principles known as the R framework, which has evolved from the basic 3Rs (reduce, reuse, recycle) to more comprehensive models such as the 5Rs, 6Rs, 9Rs, and 10Rs. For instance, Jawahir and Bradley (2016) expanded the 3Rs to include rethink and repair, while

Tserng et al. (2021) introduced the 6Rs, which include reuse, recycle, redesign, remanufacture, reduce, and recover. The 9Rs framework, as proposed by the Ellen MacArthur Foundation (2020), adds refuse, refurbish, repurpose, and recover energy to the list. Similarly, Van Buren et al. (2016) introduced the 10Rs, which include recover, recycle, repurpose, and remanufacture. Other principles within the R framework include endurance, resell, resource efficiency, disassembly, lifetime extension, waste management, end-of-life management, design for zero waste, and design for recycling (Boyer et al., 2021; Ortiz-de-Montellano & van der Meer, 2022; Kristensen & Mosgaard, 2020; Zaman et al., 2023).

The rationale for adopting CE principles lies in their potential to address pressing global challenges such as resource scarcity, biodiversity depletion, waste generation, and environmental pollution. By keeping materials in a closed-loop production system for an extended period, the CE reduces the rate and volume of waste generation and minimizes the depletion of natural resources (EMF, 2020). Furthermore, the adoption of the R framework is expected to lead to a cleaner environment and more sustainable production practices.

1.2 Statement of the Problem

The construction industry is among the largest consumers of natural resources and one of the leading generators of construction and demolition (C&D) waste globally (Ellen MacArthur Foundation [EMF], 2020). Although circular economy principles have been promoted to improve resource efficiency and minimize waste, approximately 60% of C&D waste worldwide is still disposed of in landfills, contributing to environmental degradation and resource depletion (Guerra et al., 2021; Yu, Mok, & Wong, 2023). In Kenya, rapid urbanization and infrastructure development have increased the volume of construction waste, yet sustainable waste management practices remain inadequately implemented due to weak policy enforcement, limited recycling infrastructure, low adoption of environmental management systems, and insufficient stakeholder commitment (Onkangi et al., 2018; Tanui, 2019). While previous studies have demonstrated the potential of circular economy practices to improve sustainability, most have focused on developed countries and manufacturing industries, leaving limited empirical evidence on their application within the construction sector in developing economies (Hart, 1995; Sassi, 2004; Favi et al., 2017). Consequently, the influence of the Circular Economy Rs Framework (Reduce, Reuse, Recycle, and Redesign) on the sustainability of Kenya's built environment remains inadequately understood. This study therefore seeks to establish the relationship between the Circular Economy Rs Framework and sustainability in Kenya's construction industry to provide evidence that can inform policy, enhance resource efficiency, and promote sustainable construction practices.

2. Literature Review

The construction industry is widely recognized as one of the largest consumers of natural resources and a major contributor to construction and demolition (C&D) waste globally. Traditional linear production systems characterized by the "take–make–dispose" model have resulted in increased resource depletion, environmental degradation, and greenhouse gas emissions. Consequently, the Circular Economy (CE) has emerged as an alternative economic model that seeks to retain materials within production systems for as long as possible through strategies such as reducing, reusing, recycling, and redesigning products and processes (Geissdoerfer et al., 2017; Ellen MacArthur Foundation [EMF], 2020).

Unlike the linear economy, the circular economy promotes resource efficiency by minimizing waste generation while maximizing the value of products throughout their life cycle. Studies have demonstrated that the adoption of circular economy principles in construction contributes to reduced environmental impacts, improved economic performance, and enhanced social sustainability (Al Sholi et al., 2023). Nevertheless, implementation remains uneven, particularly in developing countries where institutional, technological, and financial barriers continue to impede adoption.

The reduce principle focuses on preventing waste generation through efficient planning, procurement, and resource utilization. Ajayi and Oyedele (2018) observed that waste reduction begins during the procurement stage through accurate quantity estimation, supplier collaboration, standardized designs, and just-in-time material delivery. Similarly, Dainty and Brooke (2004) argued that lean construction practices significantly reduce material wastage by eliminating unnecessary activities and improving inventory management.

Recent studies further demonstrate that digital technologies such as Building Information Modelling (BIM), artificial intelligence, and digital supply chain management improve forecasting accuracy and minimize material losses during construction projects (Ikpe & Shamsuddoha, 2024). Although these approaches have been successfully implemented in developed economies, evidence from Kenya remains limited, indicating the need for empirical studies examining their effectiveness within local construction projects.

Reuse extends the useful life of construction materials by using them again without substantial processing. According to Patil (2018), reusable construction materials include bricks, steel, timber, concrete, glass, reinforcement bars, and other demolition materials that remain structurally sound. Reusing these materials significantly reduces demand for virgin resources while lowering construction costs.

Huovila and Westerholm (2022) reported that reuse substantially reduces carbon emissions, with reused bricks lowering emissions by approximately 77% and crushed concrete reducing emissions by over 90%. Cooper and Gutowski (2017) further argued that reuse contributes to resource conservation by extending product life cycles and reducing landfill disposal. Despite these documented benefits, reuse practices remain uncommon in many developing countries due to inadequate material recovery systems, absence of quality standards, and negative perceptions regarding reclaimed materials.

Recycling involves processing construction waste into secondary raw materials suitable for new construction activities. Recycling reduces pressure on natural resources while minimizing waste disposal and environmental pollution (Yap, 2011). Field and Sroufe (2007) found that recycled materials provide both environmental and economic benefits by reducing extraction of virgin materials and lowering production costs.

Yuik et al. (2023) emphasized that successful recycling depends upon efficient reverse logistics, stakeholder collaboration, and supportive government policies. Likewise, Jäger-Roschko et al. (2020) noted that recycling performance improves considerably when manufacturers, contractors, transporters, and recyclers coordinate material recovery activities. Nevertheless, recycling infrastructure remains inadequate across many African countries, limiting the practical implementation of circular economy initiatives within the construction sector.

Redesign represents a proactive approach whereby buildings and construction materials are intentionally designed to facilitate future reuse, repair, disassembly, and recycling. Sassi (2004) argued that sustainable building design should emphasize resource efficiency, adaptability, modular construction, and waste minimization throughout the building life cycle.

Similarly, Favi et al. (2017) proposed integrating End-of-Life considerations during product design to improve recyclability and material recovery. Design for disassembly enables buildings to be dismantled with minimal material damage, thereby supporting circular resource flows. Although redesign has gained increasing attention in developed countries, its application within Kenya's construction industry remains relatively unexplored due to limited technical expertise and inadequate regulatory incentives.

Sustainability within the construction industry encompasses environmental protection, economic viability, and social well-being. Papadopoulos et al. (2016) argued that sustainable construction requires efficient management of materials, energy, waste, and stakeholder relationships throughout project life cycles. The triple bottom line framework further emphasizes balancing environmental, economic, and social objectives to achieve long-term sustainability (Belvedere & Grando, 2017).

Research demonstrates that organizations adopting circular economy practices experience reduced operational costs, improved resource efficiency, enhanced corporate reputation, and increased competitiveness (Jedynak, 2023). However, sustainability implementation remains constrained by fragmented supply chains, inadequate policy enforcement, financial limitations, and insufficient awareness among industry stakeholders, particularly in developing countries.

Existing literature consistently demonstrates that the Circular Economy Rs Framework contributes to sustainable construction through waste reduction, resource efficiency, and environmental protection. However, most empirical studies have been undertaken in developed countries and manufacturing sectors, with limited focus on construction industries in Sub-Saharan Africa. Furthermore, previous research has largely examined individual circular economy strategies rather than investigating the combined influence of Reduce, Reuse, Recycle, and Redesign on sustainability outcomes. There is therefore insufficient empirical evidence regarding the relationship between the Circular Economy Rs Framework and sustainability within Kenya's construction industry. This study seeks to address this gap by examining how the integrated application of the Rs Framework influences sustainability in the Kenyan built environment. The conceptual Framework is presented in Figure 1

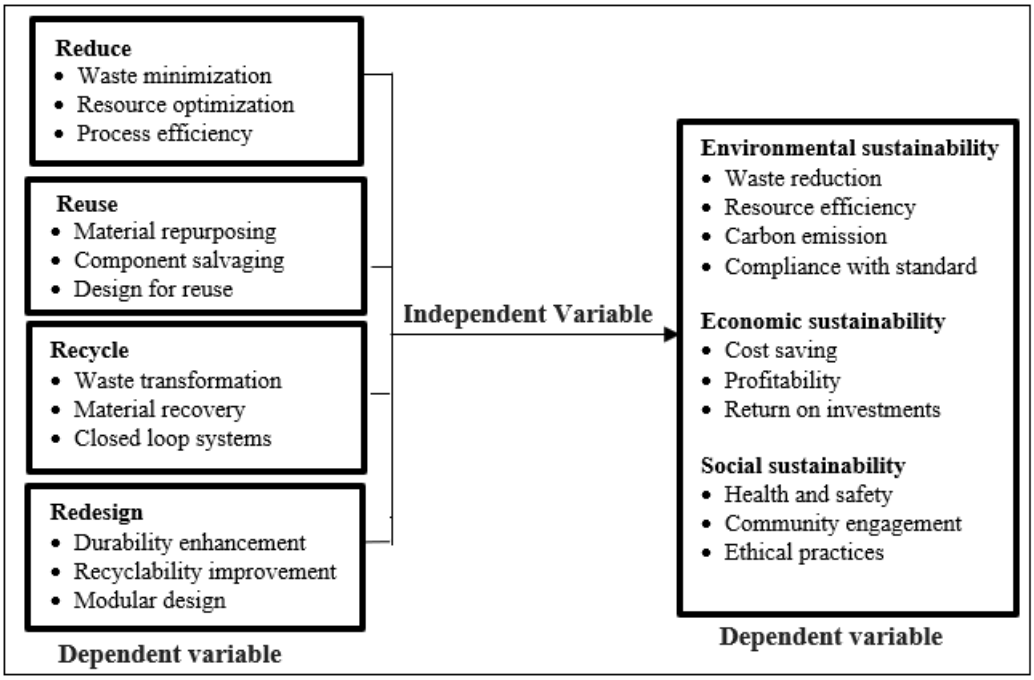

Figure 1: Conceptual Framework

3. Methodology

This study adopted a quantitative research approach using a cross-sectional correlational research design to examine the relationship between the Circular Economy R Framework (Reduce, Reuse, Recycle, and Redesign) and sustainability in the construction industry in Kenya. A correlational design was considered appropriate because it facilitates the examination of relationships among variables without manipulating the study environment (Creswell & Creswell, 2020). The cross-sectional approach enabled data to be collected from respondents at a single point in time, making it suitable for assessing current sustainability practices within construction firms (Saunders, Lewis, & Thornhill, 2019).

The target population comprised construction professionals operating within the Nairobi Metropolitan region, including engineers, contractors, project managers, architects, and suppliers registered with the Kenya Association of Manufacturers (KAM) and the National Construction Authority (NCA). These professionals were selected because of their direct involvement in construction activities, resource utilization, and implementation of sustainable construction practices. The study population consisted of 150 respondents.

A stratified random sampling technique was employed to ensure proportional representation of all professional categories within the construction industry. The sample size of 109 respondents was determined using the Yamane (1967) formula at a 95% confidence level and a 5% margin of error. Stratified sampling minimized sampling bias and improved the representativeness of the study findings (Etikan & Bala, 2020).

Primary data were collected using a structured questionnaire comprising closed-ended and open-ended questions. Closed-ended items were measured on a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree) to assess respondents' perceptions of the four Circular Economy R Framework dimensions and sustainability practices. The questionnaire was subjected to a pilot test involving construction professionals in Machakos County, an area excluded from the main study. Instrument reliability was assessed using Cronbach's alpha coefficient, with values of 0.70 and above considered acceptable (Hair et al., 2021). Content and construct validity were established through expert review by the research supervisor to ensure that the questionnaire adequately measured the study constructs.

Collected data were coded, cleaned, and analyzed using the Statistical Package for Social Sciences (SPSS) version 26. Descriptive statistics, including frequencies, means, standard deviations, and percentages, were used to summarize respondent characteristics and study variables. Pearson correlation analysis was performed to determine the strength and direction of relationships among variables, while multiple linear regression analysis was used to examine the influence of the Circular Economy R Framework dimensions on sustainability. The regression model was specified as:

$$Y = \beta0 + \beta1Reduce + \beta2Reuse + \beta3Recycle + \beta4Redesign + \varepsilon$$

where Y represents sustainability, β_0 is the intercept, β_1–β_4 are regression coefficients, and ε is the error term.

To ensure the robustness of the regression model, diagnostic tests were conducted. Normality of residuals was assessed using the Shapiro–Wilk test, multicollinearity was examined using the Variance Inflation Factor (VIF), heteroscedasticity was evaluated using the Breusch–Pagan test, and autocorrelation was assessed using the Durbin–Watson statistic. These diagnostic procedures ensured that the assumptions underlying multiple linear regression were satisfied, thereby enhancing the validity and reliability of the study findings (Field, 2019; Hair et al., 2021).

4. Findings and Discussions

4.1 Correlation Analysis

Pearson correlation analysis was conducted to examine the relationships between the Circular Economy R Framework dimensions (Reduce, Reuse, Recycle, and Redesign) and sustainability in the construction industry. The results are presented in Table 1.

Table 1: Pearson Correlation Matrix

Variable	1	2	3	4	5
1. Sustainability	1.000				
2. Reduce	0.861**	1.000			
3. Reuse	0.873**	0.871**	1.000		
4. Recycle	0.819**	0.787**	0.784**	1.000	
5. Redesign	0.794**	0.651**	0.661**	0.684**	1.000

Note: p < 0.01.

The findings indicate that all four Circular Economy practices were positively and significantly associated with sustainability. Reuse exhibited the strongest correlation with sustainability (r = 0.873), followed by Reduce (r = 0.861), Recycle (r = 0.819), and Redesign (r = 0.794). These results suggest that increased implementation of Circular Economy practices is associated with improved sustainability performance in construction firms. The significant correlations among the independent variables further indicate that the four practices complement one another in supporting sustainable construction.

4.2 Regression Analysis

Simple regression analysis was first performed to examine the individual influence of each Circular Economy practice on sustainability before estimating the combined multiple regression model. Table 2 summarizes the regression results.

Table 2: Summary of Simple Regression Results

Predictor	R	R^2	β	t	F	p-value
Reduce	0.861	0.742	0.861	15.071	227.128	<0.001
Reuse	0.873	0.762	0.873	15.910	253.143	<0.001
Recycle	0.819	0.672	0.819	12.709	161.511	<0.001
Redesign	0.794	0.630	0.794	11.604	134.656	<0.001

The results demonstrate that each Circular Economy practice significantly predicts sustainability. Reuse explained the highest proportion of variance in sustainability (R^2 = 0.762), indicating that extending the useful life of construction materials and components contributes substantially to

sustainable construction. Reduce ranked second ($R^2 = 0.742$), highlighting the importance of minimizing material consumption and waste generation. Recycle explained 67.2% of the variation in sustainability, while Redesign accounted for 63.0%, confirming that eco-design and material recovery practices also contribute significantly to sustainability outcomes.

4.3 Multiple Regression Analysis

A multiple regression model was estimated to determine the combined influence of the four Circular Economy practices on sustainability. The findings are presented in Table 3.

Table 3: Multiple Regression Results

Variable	β	t	p-value
Constant		10.599	<0.001
Reduce	0.258	2.917	0.005
Reuse	0.329	3.722	<0.001
Recycle	0.149	2.040	0.045
Redesign	0.307	5.276	<0.001

Model Statistics

R	R^2	Adjusted R^2	F	Sig.
0.935	0.875	0.868	132.812	<0.001

The multiple regression model was statistically significant ($F = 132.812$, $p < 0.001$), indicating that the Circular Economy R Framework collectively predicts sustainability in the construction industry. The model explained 87.5% of the variation in sustainability ($R^2 = 0.875$), suggesting excellent explanatory power.

Among the four predictors, Reuse recorded the highest standardized regression coefficient ($\beta = 0.329$), making it the strongest predictor of sustainability. Redesign followed closely ($\beta = 0.307$), demonstrating that integrating sustainability principles during the design stage substantially enhances environmental performance. Reduce also had a significant positive influence ($\beta = 0.258$), indicating that minimizing material consumption and preventing waste generation improves sustainability outcomes. Although Recycle had the smallest coefficient ($\beta = 0.149$), its effect remained statistically significant, confirming that recycling contributes meaningfully to sustainability when implemented alongside other Circular Economy practices.

The findings demonstrate that the Circular Economy R Framework significantly enhances sustainability in Kenya's construction industry. The results further indicate that the greatest sustainability gains are achieved when Reduce, Reuse, Recycle, and Redesign strategies are implemented as an integrated system rather than as isolated initiatives.

5. Discussions

The findings demonstrate that the Circular Economy R Framework significantly enhances sustainability in Kenya's construction industry. Correlation analysis revealed strong positive associations between all four Circular Economy practices (Reduce, Reuse, Recycle, and Redesign) and sustainability, indicating that increased adoption of these practices is associated with improved environmental, economic, and operational performance. These findings support the fundamental principles of the Circular Economy, which advocate for resource efficiency, waste minimization, and the continuous circulation of materials within production systems (Geissdoerfer et al., 2017).

Among the four dimensions, Reuse emerged as the strongest predictor of sustainability. This finding suggests that extending the useful life of construction materials through recovery, refurbishment, and repeated utilization offers substantial sustainability benefits by reducing demand for virgin materials, lowering waste disposal, and minimizing environmental impacts. The finding corroborates previous studies by Huovila and Westerholm (2022) and Cooper and Gutowski (2017), who reported that material reuse significantly reduces carbon emissions and resource consumption while improving construction efficiency.

The study also established that Reduce has a significant positive influence on sustainability. Waste prevention through efficient planning, lean construction practices, optimized procurement, and improved material utilization contributes substantially to sustainable construction outcomes. This finding agrees with Ajayi and Oyedele (2018), who found that effective planning and procurement reduce construction waste and improve project performance. Similarly, Ikpe and Shamsuddoha (2024) observed that lean management and digital technologies enhance resource efficiency and reduce unnecessary material losses.

The positive effect of Recycle confirms that recovering construction and demolition waste for subsequent use contributes significantly to sustainability by reducing landfill disposal and conserving natural resources. Although recycling exhibited the lowest standardized effect in the combined model, it remained statistically significant, indicating that recycling complements rather than replaces other Circular Economy practices. These findings support Field and Sroufe (2007) and Yap (2011), who concluded that recycling improves environmental performance and supports sustainable resource management.

Furthermore, Redesign was found to significantly enhance sustainability, highlighting the importance of integrating sustainability considerations during the design phase of construction projects. Designing buildings for durability, adaptability, disassembly, and material recovery improves resource efficiency throughout the building life cycle. This finding is consistent with Sassi (2004) and Favi et al. (2017), who argued that eco-design is fundamental to achieving long-term circularity within the construction industry.

The multiple regression model demonstrated that the four Circular Economy practices jointly explained 87.5% of the variation in sustainability, suggesting that sustainability is best achieved through an integrated implementation of the Circular Economy R Framework. This finding reinforces the proposition by Geissdoerfer et al. (2017) that circular economy strategies generate greater environmental and economic benefits when implemented collectively rather than independently.

6. Conclusions

This study examined the relationship between the Circular Economy R Framework and sustainability in Kenya's construction industry. The findings demonstrate that Reduce, Reuse, Recycle, and Redesign all have positive and statistically significant effects on sustainability. Collectively, these practices explain a substantial proportion of sustainability performance, confirming that the Circular Economy provides an effective framework for promoting sustainable construction.

Among the four practices, Reuse was identified as the strongest predictor of sustainability, followed by Redesign, Reduce, and Recycle. These findings suggest that extending the life cycle of construction materials, incorporating sustainability into building design, minimizing resource consumption, and improving recycling systems are essential for enhancing environmental performance and resource efficiency.

The study provides empirical evidence that adopting an integrated Circular Economy approach can significantly improve sustainability within Kenya's construction sector. The findings contribute to the growing body of knowledge on circular economy implementation in developing countries and provide practical evidence to support policy development and sustainable construction practices.

7. Recommendations

Based on the findings, the study makes the following recommendations:

1) Construction firms should prioritize the adoption of integrated Circular Economy practices by simultaneously implementing Reduce, Reuse, Recycle, and Redesign strategies rather than relying on isolated waste management initiatives.
2) Government agencies, including the National Construction Authority (NCA) and relevant environmental regulators, should strengthen policies and enforcement mechanisms that promote circular construction practices through incentives, standards, and regulatory frameworks.
3) Construction organizations should invest in design innovations, Building Information Modelling (BIM), and digital technologies that facilitate material optimization, waste prevention, and design for disassembly.
4) The construction industry should establish efficient material recovery and reuse systems to increase the utilization of reclaimed construction materials and reduce dependence on virgin resources.
5) Capacity-building programmes should be developed to improve awareness and technical competencies among construction professionals regarding Circular Economy principles and sustainable construction practices.
6) Future research should examine additional factors influencing Circular Economy adoption, including organizational culture, government policy, technological innovation, supply chain collaboration, and financial incentives. Comparative studies involving different regions and longitudinal research designs are also recommended to enhance understanding of Circular Economy implementation in developing countries.

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