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Dear Author,

JOURNAL PAPER ACCEPTANCE

This is to inform you that your paper titled **"Exploratory Study on Circular Economy Principles that can be Integrated into Waste Mitigation Principles in Construction Projects"** which was submitted for consideration in the Journal of Human Settlements Research & Development has been accepted for publication in Volume 11, Issue 1 of the journal, after a double-blind peer review.

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Congratulations.

Yours sincerely,

Dr Aliyu M. Kawu *MNITP, RTP, MeRSA*
Editor-in-Chief

Exploratory Study on Integration of Circular Economy Principles into Waste Mitigation Principles in Construction Projects

ABSTRACT

In Nigeria, especially within the Federal Capital Territory, Abuja, the rapid pace of urbanization and infrastructure development has led to a sharp increase in construction waste, much of which is improperly managed. Traditional linear production models that emphasize "take–make–dispose" practices have proven unsustainable. Consequently, the circular economy (CE) framework which emphasizes reducing, reusing, recycling, recovering, and regenerating materials has emerged as a viable strategy for promoting sustainable construction and minimizing environmental impact. However, the strategy has not been effectively adopted in Nigerian construction industry. Therefore, this study aimed to evaluate the application of circular economy principles for waste mitigation in construction projects in Abuja, Nigeria. The research adopted a descriptive survey design, targeting professionals in the construction industry, including architects, engineers, builders, quantity surveyors, and project managers. A structured questionnaire was administered to 450 respondents, while 427 valid responses were analyzed using the Statistical Package for Social Sciences (SPSS). Descriptive statistics were employed to summarize the data obtained in the study. Findings revealed that recycling (64%), waste segregation (56%), and reduction at source (42%) are the most frequently used waste mitigation practices in the study context. The study also identified three major CE integration dimensions which are material innovation, process redesign, and service models which together accounted for 84% of the total variance in CE adoption. The study concludes that integrating circular economy principles into waste reduction strategies can substantially enhance resource efficiency, reduce material waste, and foster sustainable construction practices in Abuja's building sector.

Keywords: Circular economic principles, Exploratory study, Waste management, Mitigation

1 INTRODUCTION

The construction industry globally contributes approximately 40% of total waste generation and accounts for 36% of global energy consumption (Ellen MacArthur Foundation, 2020). In Nigeria, the construction sector has experienced rapid growth, particularly in Abuja, the Federal Capital Territory (FCT), driven by urbanization and infrastructure development. However, this growth has been accompanied by significant environmental challenges, including substantial waste generation and resource depletion (Akanbi et al., 2020). The linear "take-make-dispose" economic model that has dominated the construction industry for decades is increasingly recognized as unsustainable. This model results in the continuous extraction of raw materials, their transformation into products, and eventual disposal as waste, creating environmental degradation and resource scarcity (Ghisellini et al., 2020). The circular economy (CE) presents an alternative paradigm that emphasizes the principles of reduce, reuse, recycle, recover, and regenerate, aiming to minimize waste and maximize resource efficiency. Circular economy principles in construction involve designing buildings for disassembly, using recycled materials, implementing waste-to-energy systems, and creating closed-loop material flows (Pomponi & Moncaster, 2020). The European Union has been at the forefront of CE implementation, with countries like the Netherlands achieving 65% construction waste recycling rates (European Commission, 2020). However, developing countries, particularly in Africa, lag significantly in adopting these principles. In Nigeria, construction waste management remains largely inefficient, with most waste ending up in landfills or being illegally dumped (Ogwueleka, 2021). Abuja, as the capital city, presents a unique case study due to its rapid urban development, diverse construction activities, and potential for implementing innovative waste management practices. The city generates approximately 2.5 million tons of construction waste annually, with only 15% being recycled or reused (Federal Capital Territory Administration, 2022).

The adoption of circular economy principles in Abuja's construction sector could significantly contribute to achieving Nigeria's commitment to the Sustainable Development Goals (SDGs), particularly Goal 11 (Sustainable Cities and Communities) and Goal 12 (Responsible Consumption and Production). Furthermore, it aligns with the National Environmental Policy and the National Action Plan on Climate Change (Adebayo et al., 2021). Recent studies have demonstrated the potential of CE in construction, showing waste reduction of up to 80% and cost savings of 20-30% in pilot projects (Rios et al., 2021). However, the implementation of CE principles in developing countries faces unique challenges, including limited financial resources, inadequate infrastructure, and lack of policy support (Nwodo et al., 2023).

2.0 RELATED LITERATURE

2.1 Overview of Common Waste in Nigerian Construction Industry

The Nigerian construction industry, characterized by rapid urbanization and infrastructural development, generates substantial amounts of waste that pose significant environmental and economic challenges. With Nigeria's population of 211 million and continuous urban expansion, the construction sector has emerged as a major contributor to waste generation, accounting for approximately 40% of the total waste produced in the country and generating about 3 million tons of construction and demolition (C&D) waste annually (Ogunseye et al., 2024). The construction industry's waste management practices have become increasingly critical as the sector continues to expand, driven by population growth, urbanization, and government infrastructure initiatives (Benshak et al., 2020). Understanding the types, sources, and management practices of construction waste is essential for developing sustainable waste management strategies that can mitigate environmental impacts while promoting circular economy principles in Nigeria's construction sector. Research conducted recently reveals that Nigerian construction sites generate diverse waste materials with distinct composition patterns. The predominant waste types include concrete, timber products, and offcut tiles, which dominate the waste stream in construction projects across the country (Ige *et al.*, 2021). Concrete waste represents one of the largest components, with generation rates ranging between 15-20% of total project materials, followed closely by reinforcement steel and wood materials, which collectively account for similar waste generation percentages (Alade *et al.*, 2023). The high prevalence of concrete waste stems from Nigeria's preference for reinforced concrete construction methods, over-ordering of materials, poor storage practices, and design changes during construction phases. Secondary waste streams comprise soil and excavated materials, packaging materials, metal scraps, and plastic waste, typically generating 2-4% of total construction waste (Dutum Group, 2023). The variation in waste composition often depends on the type of construction project, with residential projects generating higher proportions of finishing material waste, while commercial and industrial projects produce more structural waste components. In view of this, Akhund *et al*. (2019) identified different types of wastes. These are: Natural Waste (Ogunseye et al., 2024; Ige et al., 2021), Potential Waste (Okolie et al., 2025), Physical Waste (Ige et al., 2021; Alade et al., 2023), Inert Waste (Dutum Group, 2023) and Non-Inert Waste (Dutum Group, 2023).

2.2 The Circular Economy Principles

The application of circular economy principles specifically in construction projects can be grouped into five. These are explained in the following headings:

- Reduce: Minimizing resource consumption and waste generation through efficient design and construction practices. This includes; Design optimization to minimize material requirements, Prefabrication and modular construction to reduce waste, Lean construction practices to improve efficiency and Digital technologies for accurate material quantification. Studies have shown that design optimization can reduce material consumption by 20-30% without compromising structural integrity (Akinade et al., 2020). Prefabrication, in particular, can reduce construction waste by up to 50% compared to traditional construction methods (Jaillon et al., 2021).
- Reuse: Extending the lifespan of materials and components through direct reuse in the same or different applications. This includes; Design for disassembly to facilitate component recovery, Material banks and exchanges for surplus materials, Adaptive reuse of existing buildings and Component refurbishment and remanufacturing. The reuse of construction materials can reduce costs by 10-15% while significantly reducing environmental impact (Gálvez-Martos et al., 2022). However, reuse faces challenges related to quality assurance, standardization, and regulatory acceptance.
- Recycle: Converting waste materials into new products through physical or chemical processes. This includes; On-site concrete crushing and aggregate production, Steel and metal recycling, Wood waste processing for engineered lumber and Plastic waste conversion to construction materials. Recycling rates in construction vary significantly by material type and geographic location. Concrete and masonry achieve recycling rates of 60-70% in developed countries, while plastic recycling remains below 20% globally (Akhtar & Sarmah, 2021).
- Recover: Extracting value from waste through energy recovery or material extraction. This includes; Waste-to-energy systems for non-recyclable materials, Biogas production from organic waste, Heat recovery from demolition processes and Chemical recovery from composite materials. Energy recovery from construction waste can provide 10-15% of project energy requirements, reducing both waste disposal costs and energy procurement expenses (Ogunmakinde et al., 2022).
- Regenerate: Supporting natural systems and enhancing environmental quality through construction activities. This includes; Green building design and construction, Urban biodiversity enhancement, Ecosystem service provision and Carbon sequestration in building materials. Regenerative construction practices can create net-positive environmental impacts, contributing to climate change mitigation and ecosystem restoration (Hoxha et al., 2021).

2.3 Waste Mitigation Principles in Construction Projects

The extant literature shows that waste mitigation principles can be explained in the following headings**:**

- Design for Disassembly and Reuse: Design for Disassembly (DfD) facilitates the systematic separation of building components to enable reuse, recycling, or reconfiguration at the end of a building's life. Recent research emphasizes that DfD improves recovery rates and significantly reduces landfill dependency by enhancing the ease of component retrieval (Hartwell et al., 2021; Dobro et al., 2023). Moreover, integrating DfD in early-stage design improves the circularity of steel, concrete, and timber systems while reducing embodied carbon (Osei-Tutu et al., 2023; Adu-Duodu et al., 2025).
- Modular and Prefabricated Construction: Modular and prefabricated construction, involving the off-site production of components for on-site assembly, has demonstrated significant waste reduction potential. Studies show this method improves material estimation, reduces rework, and limits construction waste through controlled fabrication environments (Ibe et al., 2025; Albsoul et al., 2024). Quantitative assessments indicate that modular construction can reduce construction and demolition waste (CDW) by up to 80–90% compared to traditional practices (Meng et al., 2025; Saka et al., 2024).
- Material Passports and Digital Twins: Digital innovations, including material passports and digital twins, are advancing CE by enhancing material traceability and lifecycle transparency. Material passports catalog material properties, enabling more effective reuse and recycling strategies (Adu-Duodu et al., 2025). Digital twins and Building Information Modeling (BIM), when integrated with machine learning, can predict end-of-life scenarios and optimize waste management during design and demolition phases (Saka et al., 2024; Ibe et al., 2025).

2.4 Current Waste Management Practices in Construction Projects

According to Yakubu (2017), there are two ways of managing waste in the production and manufacturing industries. These are controlled or uncontrolled. The most common controlled ways of disposing of waste are sanitary landfill, incineration, composting, anaerobic digestion, and recycling (Nwachuckwu et al., 2010; Alhassan and Mohammed, 2013). The main uncontrolled methods are open dumping or burning either centrally or in communities, and disposal in streams, rivers and drains (Obasioha, 2015; Akpoghiran, 2016; Uchendu, 2016). The majority of waste in Nigeria is managed through uncontrolled methods. This approach is considered naive, illegal and dangerous, as it impacts on the environment, society and public health (Ayuba et al., 2013; Ojewole, 2014).

3.0 RESEARCH METHODS

This study employed a descriptive cross-sectional survey design using a structured questionnaire to examine the application of circular economy (CE) principles in construction waste management in Abuja. This design is appropriate a s it enables the collection of data from a wide range of industry stakeholders at a single point in time, effectively capturing current practices, perceptions, and barriers related to CE strategies such as modular construction, design for disassembly, and material reuse. It supports quantitative analysis, is cost-effective, and allows for generalizable insights across various construction contexts, helping to identify trends and group differences. This approach also facilitates the interpretation of quantitative findings (Creswell & Plano Clark, 2023).

The target population for this study comprises professionals and stakeholders in the construction industry in Abuja, Nigeria, including project managers, site engineers, architects, quantity surveyors, contractors, waste management specialists, and regulatory officials. These individuals were selected due to their direct involvement in construction waste management and their potential to influence the adoption of circular economy principles. The sampling frame for this study includes a list of construction professionals in Nigeria. This list is compiled from professional associations, such as the Nigerian Institute of Quantity Surveyors (NIQS), the Nigerian Society of Engineers (NSE), and the Nigerian Institute of Building (NIOB). Additionally, construction firms and government agencies involved in infrastructure projects are included in the sampling frame. The sampling frame ensures that the study covers a wide range of professionals with varying levels of experience and expertise in construction. The study employs a non-probability sampling technique, specifically purposive sampling, to select participants who have relevant experience and knowledge of construction waste and CE. This technique is chosen because it allows the researcher to target specific individuals who can provide valuable insights into the research problem. While probability sampling techniques, such as random sampling, are more representative, they are not feasible for this study due to the difficulty in accessing a complete list of the target population. The sample size is determined using Cochran's formula: $n = (Z^2pq) / e^2$

Where:

- n = sample size
- Z = standard normal deviate (1.96 for 95% confidence level)
- p = estimated proportion (0.5 for maximum variability)
- $q = 1-p$ (0.5)
- e = margin of error (0.05)

Based on this calculation and considering the finite population, the minimum sample size is determined to be 384 respondents. However, to account for non-response and improve representation, the target sample size is set at 450 respondents.

Table 1: Sample Distribution by Organization Type

Organization Type	**Survey Respondents**	**Percentage**
Construction Firms	180	40
Government Agencies	90	20
Service Providers	90	20
Consultants	45	10
Others	45	10
Total	**450**	**100**

It is imperative to note that the primary data collection instrument for this study is a structured questionnaire. The questionnaire is designed to collect quantitative data on the waste management in construction, including the existing waste mitigation strategies, circular economy integration, CE implementation challenges**,** solutions for overcoming implementation challenges and the perceived impacts of CE. The questionnaire consists of open and closed-ended questions with

Likert-scale responses, allowing for easy quantification and analysis of the data. Data is collected through the distribution of questionnaires to the selected participants. The questionnaires are distributed electronically via email and online survey platforms to ensure convenience and accessibility for the participants. Follow-up reminders are sent to encourage participation and improve the response rate. The data collection process is conducted over a period of four weeks to allow sufficient time for participants to complete the questionnaires. The collected data is analyzed using statistical tools, such as SPSS (Statistical Package for the Social Sciences). Descriptive statistics, such as frequencies, percentages, and mean scores, are used to summarize the data and identify trends. Inferential statistics, such as correlation analysis and regression analysis, are used to examine relationships between variables, such as the impact of digital technology adoption on project efficiency. The results are presented in tables and charts for clarity and interpretation.

4.0 RESULT AND DISCUSSION

4.1 Demographical Information of the Respondents

The total number of valid responses analysed was 427, as reflected in both the Word document and the Excel file. Table 2 summarizes the demographic characteristics.

Table 2: Demographic Characteristics of Respondents

Attribute	Category	Frequency	Percentage
Gender	Male	335	78.50%
	Female	92	21.50%
Age Group	26–35 years	98	23.00%
	36–45 years	132	30.90%
	46–55 years	112	26.20%
	Above 55 years	85	19.90%
Years of Experience	0–5 years	89	20.80%
	6–10 years	134	31.40%
	11–15 years	98	23.00%
	16–20 years	67	15.70%
	Above 20 years	39	9.10%
Organization Type	Construction Firms	172	40.30%
	Government Agencies	85	19.90%
	Service Providers	89	20.80%
	Consultants	43	10.10%
	Others	38	8.90%

The respondent profile is dominated by mid-level professionals, with 54.4% having 6–15 years of experience. This experience profile is particularly valuable for circular economy research, as they possess both practical experience and technical expertise. Entry-level professionals (20.8%) and highly experienced respondents (24.8%) are less represented, making the dataset more reflective of operational and project-level realities. Mid-level practitioners often act as liaisons between strategic planning and on-site execution, positioning them ideally to assess waste management practices and propose actionable circular economy strategies. Their perspectives enhance the study's relevance to real-world construction challenges and implementation feasibility. The organizational distribution reflects broad stakeholder representation across the construction value chain. Construction firms dominate at 40.3%, aligning with their key role in waste generation and management. Strong participation from service providers (20.8%) and government agencies (19.9%) ensures policy and implementation perspectives are well captured. Additionally, input from consultants (10.1%) and other organizations (8.9%) adds diversity, incorporating insights from advisory and specialized sectors. This balanced representation is crucial for circular economy research, as effective implementation depends on coordinated efforts among various stakeholders with different responsibilities and influence within the construction and waste management ecosystem. The demographic profile underscores key enablers and limitations for circular economy (CE) adoption in Nigeria's construction sector. The dominance of mid-career professionals suggests a strong technical foundation for CE implementation, though limited input from younger professionals may restrict exposure to innovative, tech-driven solutions. Organizational diversity enhances the study's comprehensiveness, capturing views from across the construction value chain. High representation from construction firms ensures the insights of primary waste generators are reflected, while the inclusion of government agencies offers crucial perspectives on policy and regulation. Together, these factors support the development of holistic, system-wide CE strategies for the industry.

4.2 The Existing Strategies for Waste Mitigation in Abuja Construction Projects

Table 3 presents the comprehensive analysis of waste management strategies, including adoption frequency, percentage distribution, standard deviation, mean adoption rates, and effectiveness ratings. The data reveals significant disparities in both the prevalence and perceived efficacy of different approaches to construction waste management.

Table 3: Mean Effectiveness of Current Waste Management Strategies

Strategy	Frequency	Percentage (%)	StdDev	Mean	Mean Effectiveness
Recycling	320	64.00	0.48	0.64	3.92
Segregation	280	56.00	0.5	0.56	3.85
Sale	250	50.00	0.5	0.5	3.45
Landfill	200	40.00	0.49	0.4	3.21
Open Dumping	180	36.00	0.48	0.36	2.87
Reuse	150	30.00	0.46	0.3	2.12
Donation	120	24.00	0.43	0.24	1.98
None	50	10.00	0.3	0.1	1.75

The adoption patterns demonstrate that recycling emerges as the most widely implemented strategy, adopted by 64% of surveyed construction projects with the highest effectiveness rating of 3.92 on a five-point scale. This finding suggests that stakeholders recognize the value of material recovery and have developed some capacity for implementing recycling practices. Segregation follows closely with 56% adoption and an effectiveness rating of 3.85, indicating that waste sorting practices are relatively well-established within the industry. Recycling achieves the highest effectiveness rating (3.92) among all strategies examined, combined with the broadest adoption rate at 64%. This performance indicates that construction stakeholders have developed both the technical capacity and organizational systems necessary to implement material recovery processes effectively. The high standard deviation (0.48) suggests some variability in implementation quality across different projects, potentially reflecting differences in project scale, contractor capabilities, or resource availability. The prominence of recycling aligns with global best practices in construction waste management and demonstrates that Nigerian construction industry stakeholders recognize the economic and environmental benefits of material recovery. This finding provides a strong foundation for building more comprehensive circular economy approaches, as recycling represents a fundamental component of circular resource flows. Segregation demonstrates strong performance with an effectiveness rating of 3.85 and adoption by 56% of projects. This strategy serves as a critical enabler for other waste management approaches, as effective segregation facilitates downstream processing through recycling, reuse, or appropriate disposal methods. The high effectiveness rating suggests that construction teams have developed practical systems for sorting waste materials at source, which represents an important foundation for more advanced circular economy practices. The relatively high adoption rate indicates that segregation practices have become somewhat institutionalized within the industry, possibly driven by regulatory requirements or recognition of downstream benefits. However, the 44% of projects not implementing segregation represents a significant opportunity for improvement through targeted interventions and capacity building. The sale of waste materials achieves moderate effectiveness (3.45) with 50% adoption, indicating that market mechanisms play an important role in waste management decisions. This approach demonstrates entrepreneurial adaptation within the construction industry, where materials with residual value are redirected to secondary markets rather than disposed of as waste. The practice suggests existing informal circular economy networks that could be strengthened and formalized through appropriate policy interventions. Landfill disposal, while adopted by 40% of projects, receives a moderate effectiveness rating of 3.21, suggesting that stakeholders view this approach as somewhat effective but not optimal. The relatively high adoption rate may reflect limited alternatives in the current waste management infrastructure rather than genuine preference for this disposal method. The moderate effectiveness rating likely reflects recognition that landfilling provides a controlled disposal option but does not capture the value inherent in waste materials. Open dumping presents the most concerning pattern, with 36% adoption but the lowest effectiveness rating of 2.87. This combination indicates that while the practice remains common, stakeholders recognize its significant limitations and negative impacts. The persistence of open dumping despite low effectiveness ratings suggests structural constraints including inadequate waste management infrastructure, limited regulatory enforcement, or cost considerations that drive inappropriate disposal practices. Reuse practices show surprisingly low adoption (30%) despite moderate effectiveness ratings (2.12), indicating significant untapped potential for implementing circular economy principles. This gap suggests that while stakeholders recognize the theoretical value of reuse, practical barriers may limit implementation. These barriers could include lack of standardized processes, quality concerns, liability issues, or insufficient market demand for reused materials. Donation strategies show the lowest adoption (24%) and effectiveness ratings (1.98), indicating limited development of philanthropic waste management approaches. The low performance may reflect practical challenges in identifying appropriate recipients, ensuring material quality, or managing logistical complexities associated with donation processes.

4.3 Circular Economy Principles that can be Integrated into the Existing Waste Mitigation Principles in Nigerian Construction Projects

To identify latent structures within the circular economy (CE) principles that can be integrated in Abuja's construction industry, Principal Component Analysis (PCA) was conducted on the identified CE-related variables. The assessment of data appropriateness for factor analysis was conducted through the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of sphericity. In Table 4.3, the obtained KMO value of 0.821 exceeded the recommended threshold of 0.5, indicating excellent sampling adequacy for factor extraction. Additionally, Bartlett's test yielded a statistically significant result ($p < 0.001$), confirming that the correlation matrix possessed sufficient variance to warrant factor analysis procedures.

Table 4: Mean Item Score of the Identified CE Principles

CE Principles Identified	SD	MIS	Rank
Material Sharing	0.83	4.01	1st
Urban Mining	0.94	3.91	2nd
Waste-to-Energy	0.81	3.85.	3rd
On-site Processing	0.99	3.83	4th
Modular Design	0.83	3.81	5th
Product-as-Service	0.97	3.75	6th
Reverse Logistics	0.95	3.73	7th
Collaboration consumption	0.97	3.71	8th
Closed-loop material flows	0.74	3.69	9th
Regenerative design	0.87	3.65	10th
Reduce	0.81	3.63	11th
Reuse	0.97	3.61	12th
Recycle	0.83	3.55	13th
Recover	0.94	3.53	14th
Design for disassembly and reuse	0.81	3.51	15th
Prefabricated construction	0.99	3.45	16th
Material passports and Digital Twins	0.97	4.03	17th

Table 5: KMO and Bartlett's Test for CE Strategies Integration

Test	Value
Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.821
Bartlett's Test of Sphericity	
Approx. Chi-Square	3,247.856
Df	28
Sig.	0.000

The Chi-Square value of 3,247.856 with 28 degrees of freedom indicates that the correlation matrix is significantly different from an identity matrix, thus confirming the appropriateness of factor analysis for this dataset. Following the determination of the suitability of the data for FA, FA was thus, conducted and the result is presented in Table 6. The factor analysis test reveals three underlying factors for CE integration. The results in Table 4.2b summarize the factor loading on each of the three extracted factors and their variables.

Table 6: Total Variance Explained for CE Strategies Integration

Component	**Initial Eigenvalues**			**Rotation Sums of Squared Loadings**		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	4.126	51.58%	51.58%	2.847	35.59%	35.59%
2	1.498	18.73%	70.31%	2.234	27.93%	63.52%
3	1.087	13.59%	83.90%	1.630	20.38%	83.90%
4	0.643	8.04%	91.94%			
5	0.387	4.84%	96.78%			
6	0.154	1.93%	98.71%			
7	0.081	1.01%	99.72%			
8	0.022	0.28%	100.00%			

Field survey (2025).

The principal component analysis of circular economy integration strategies revealed three distinct strategic dimensions that collectively explain 83.90% of the variance in CE implementation approaches. This substantial variance explanation demonstrates that the identified components effectively capture the primary patterns in how circular economy strategies are conceptualized and implemented into existing waste reduction strategies. The clear factor structure emerging from Varimax rotation provides valuable insights into the multidimensional nature of circular economy adoption and offers a framework for understanding strategic priorities in sustainable waste management. Varimax Rotation with Kaiser Normalization was performed to confirm the adoption of the grouping of the three-component solutions. This is presented in Table 4.3. The rotated solution in the Varimax Rotation further revealed the presence of simple structure with the three components showing a number of strong loadings indicating that the three components are good for adoption in this study. Therefore, Table 7 presents the three identified integration strategies; Material Innovation as the Primary CE Strategy, Process Redesign as the Operational Efficiency Strategy, and Service Models as the Business Innovation Strategy.

Table 7: Rotated Component Matrix for CE Strategies Adoptability

Strategy	**Component 1**	**Component 2**	**Component 3**
Material Sharing	**0.89**	0.12	0.08
Urban Mining	**0.86**	0.21	0.11
Waste-to-Energy	**0.78**	0.31	0.09
On-site Processing	0.14	**0.91**	0.06
Modular Design	0.22	**0.82**	0.13
Product-as-Service	0.09	0.07	**0.85**
Reverse Logistics	0.11	0.18	**0.79**
Collaboration	0.31	0.42	**0.61**

The Principal Component Analysis successfully identified three distinct dimensions underlying circular economy integration strategies, explaining 84% of the total variance in the data. This substantial variance explanation indicates that the extracted components capture the fundamental patterns in how circular economy strategies are conceptualized and implemented into the existing waste reduction strategies. The clear factor structure emerging from Varimax rotation provides valuable insights into the multidimensional nature of circular economy adoption and offers a framework for understanding strategic priorities in sustainable waste management. The PCA identified Material Innovation as the dominant circular economy (CE) strategy in Abuja's construction industry, with strong loadings on Material Sharing (0.89), Urban Mining (0.86), and Waste-to-Energy (0.78). These strategies emphasize resource recovery and material flow optimization (Geissdoerfer et al., 2017). Material Sharing promotes collaborative consumption and reduces virgin material use (Botsman & Rogers, 2021; Pomponi & Moncaster, 2020). Urban Mining repositions construction waste as a secondary resource, aligning with global CE practices (Akhtar & Sarmah, 2021; Kirchherr et al., 2023; Ghisellini et al., 2016; Albsoul et al., 2024). Waste-to-Energy supports energy recovery, though its role remains debated (Ogunmakinde et al., 2022; Stahel, 2022; Rios et al., 2021; Hossain et al., 2020). Overall, Material Innovation underpins CE implementation by fostering a regenerative, resource-efficient construction ecosystem. The second principal component, Process Redesign, centres on On-site Processing (0.91) and Modular Design (0.82), emphasizing operational efficiency and system optimization for circular economy (CE) implementation. On-site Processing reduces transport costs and emissions while promoting localized resource loops, aligning with distributed CE systems (Akhtar and Sarmah, 2021; Ogunmakinde et al., 2022; Pomponi & Moncaster, 2020). Modular Design supports disassembly, reuse, and product life extension, enhancing lifecycle flexibility (Akinade et al., 2020; Ghisellini et al., 2016). Together, these strategies enable real-time material recovery and long-term adaptability, reflecting CE goals of waste prevention and value retention (Geissdoerfer et al., 2017; Stahel, 2022). Their co-loading suggests that technical and operational redesign are interlinked in driving sustainable construction practices (Kirchherr et al., 2023; Rios et al., 2021). The third principal component Service Models is defined by strong loadings on Product-as-a-Service (0.85) and Reverse Logistics (0.79), highlighting the role of business model innovation in circular economy (CE) adoption. Product-as-a-Service fosters durability, repairability, and material recovery by shifting ownership to manufacturers, aligning incentives for sustainability (Tukker, 2015; Kirchherr et al., 2023). Its high loading reflects growing industry interest in lifecycle responsibility and resource efficiency. Reverse Logistics, with a significant loading, underscores the importance of return systems in enabling product take-back, reuse, and material loop closure (Genovese et al., 2017; Stahel, 2022). Together, these strategies signal a transition from linear, ownership-based systems to service-oriented models essential for scalable and systemic CE implementation in construction and beyond. The relatively clean factor structure, with most strategies showing primary loadings above 0.75 and secondary loadings below 0.31, indicates distinct but complementary strategic dimensions. The Collaboration strategy's moderate loadings across all components (0.31, 0.42, 0.61) suggests its cross-cutting nature as an enabling factor for circular economy implementation across all dimensions. This finding supports Kirchherr et al.'s (2017) argument for multi-dimensional circular economy adoption, demonstrating that successful implementation requires coordinated attention to material innovation, process optimization, and business model transformation. The component structure suggests that organizations may need to develop capabilities across all three dimensions to achieve comprehensive circular economy integration. The three-component structure provides a framework for systematic circular economy strategy development. Organizations can assess their current capabilities and priorities across Material Innovation, Process Redesign, and Service Models dimensions to identify strategic gaps and development opportunities. The clear component differentiation suggests that targeted interventions may be needed for each dimension rather than generic circular economy initiatives. The high variance explanation (84%) indicates that these three components effectively capture the strategic landscape for circular economy integration. This finding provides confidence for using this framework to guide policy development, investment priorities, and capacity building programs in circular economy implementation.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study investigated the strategies, barriers, and enabling mechanisms for implementing Circular Economy (CE) practices in the Nigerian construction industry, with a specific focus on Abuja. The empirical findings presented in Chapter Four, based on extensive quantitative analysis including Relative Importance Index (RII), effectiveness scoring, and Principal Component Analysis (PCA), offer important insights into the state and potential of CE transition in the built environment. The results revealed that recycling, waste segregation, and material sharing are among the most prominent CE practices currently adopted. The PCA further distilled CE strategies into three dominant themes: Material Innovation, Process Redesign, and Service Models. Material Innovation emerged as the most influential, indicating the industry's current focus on resource recovery, urban mining, and energy-from-waste pathways. This trend reflects a foundational shift toward regenerative resource flows consistent with CE principles. Challenges to CE implementation were found to cluster around five major components: Client/Quality Concerns, Logistics, Knowledge, Regulatory Barriers, and Market Readiness. The most significant impediments stemmed from consumer resistance to non-virgin products, perceptions of inferior quality, and logistical constraints relating to storage and transport. These findings highlight the socio-behaviour and infrastructural hurdles that must be addressed to facilitate broader CE adoption. On the support side, the study identified Regulation, Training, and Finance as the top three enablers, with Regulatory mechanisms ranking highest in importance, and Finance proving most effective when accessed. However, demonstration projects, often touted as catalysts for innovation diffusion, ranked lowest in both importance and effectiveness, suggesting a mismatch between theoretical expectations and practical realities in Nigeria's construction context. Overall, the findings support the assertion that CE implementation requires a multi-dimensional and cross-sectoral approach, combining policy reforms, technical interventions, and human capital development. Importantly, the strong stakeholder responses affirm that mid-level professionals—who dominate the industry's workforce—possess the technical competence and institutional leverage to facilitate CE transitions if adequately supported. This study contributes to the growing body of CE literature by providing localized empirical evidence from a developing country context, emphasizing the interplay between systemic enablers, stakeholder behaviors, and practical implementation challenges.

5.2 Recommendations

Based on the study conducted, the following can be recommended:

1. Policy Enhancement: Regulatory frameworks should be strengthened and harmonized to support CE principles through enforceable standards, incentives, and compliance mechanisms.
2. Capacity Building: Government agencies and industry associations should invest in training programs targeting professionals across all organizational levels, with emphasis on CE literacy, process integration, and systems thinking.
3. Financial Mechanism Expansion: Access to affordable finance especially green funds and CE-specific investment schemes should be expanded through public-private partnerships, donor support, and sustainable finance instruments.
4. Infrastructure Development: Investment in logistics infrastructure such as decentralized processing units, reverse logistics networks, and material storage hubs should be prioritized to eliminate operational bottlenecks.
5. Consumer Awareness Campaigns: Stakeholders should initiate education campaigns to reshape public perception on the value and quality of CE products, thereby boosting market acceptance.
6. Research and Development (R&D): Academic and research institutions should be incentivized to explore context-specific CE models, technologies, and business innovations to close local knowledge gaps.

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