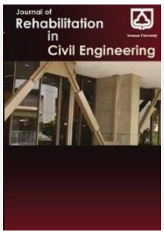

Journal of Rehabilitation in Civil Engineering

Journal homepage: https://civiljournal.semnan.ac.ir/

Strategies for Overcoming the Obstacles to Reuse and Recycling of Construction Waste Materials for Economic and Environmental Sustainability in Nigeria

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ARTICLE INFO

Article history:
Received: 25 December 2024
Revised: 15 February 2025
Accepted: 09 March 2025

Keywords:
Recycling;
Construction waste materials;
Circular economy;
Material reuse;
Construction industry.

ABSTRACT

Sustainability of building materials in construction requires minimal or no waste, which entails the reuse/recycling of construction waste materials (CWM). The construction industry generates a significant portion of solid waste across the globe. This study is aimed at identifying the potential benefits and challenges of CWM reuse/recycling in order to proffer sustainable strategies for overcoming obstacles to optimal reuse/recycling of CWM. Descriptive survey design and desk study were employed in this research. Purposive sampling techniques were used to gather data for the study, using Nigeria as a study area. Data obtained from the study were analyzed using descriptive analysis. Lack of recycling facilities with a score of 83.8% was identified as the biggest hindrance to the optimal reuse/recycling of CWM. Establishment of local recycling centers having a score of 77.1% was recognized as the most effective strategy for solving the challenges of optimal reuse/recycling of CWM. Government/government agencies/parastatals having the score of 76.5% were identified as the major key players in CWM reuse/recycling. Recommended strategies for best practices in the reuse/recycling of CWM include policy and regulations, planning, incentives, and the establishment of local recycling centers. With potential applications in other developing countries, this research offers a ground-breaking framework for encouraging sustainable construction practices and reducing construction waste in Nigeria.

E-ISSN: 2345-4423

How to cite this article:
Obianyo, I. Ijeoma, Onwualu, A. Peter, Mahamat, A. Aboubakar, Anosike-Francis, E. Nneka, Kelechi, S. Echezona and Onche, E. (2026). Strategies for Overcoming the Obstacles to Reuse and Recycling of Construction Waste Materials for Economic and Environmental Sustainability in Nigeria. Journal of Rehabilitation in Civil Engineering, 14(1), 2235 https://doi.org/10.22075/jrce.2025.36321.2235

1. Introduction

The impact of COVID-19 on the Nigerian economy has necessitated the development of robust strategies for economic recovery [1]. Global recycling efforts have been greatly disrupted by the COVID-19 epidemic, since lockdowns, social distancing measures, and staffing shortages have prompted many recycling facilities to shut down or scale back operations. Single-use plastics and other non-recyclable items, like disposable packaging and personal protective equipment (PPE), have increased because of the epidemic. This has put additional burden on recycling facilities and reduced the quality of recyclables overall. One of the viable strategies for Nigerian economic recovery is construction waste materials (CWM) reuse and recycling due to their potential to create jobs as well as preserve the environment [2,3]. This is because construction activities generate large quantities of waste which cause environmental pollution [4]. In construction projects, not all materials purchased are utilized and waste materials are generated during the use of different materials in construction sites [2]. While some of these materials are reused after sorting, others are regarded as waste materials that need to be recycled before they can be put to better use instead of dumping them in landfills [4].

In recent times, in order to reduce the impact of waste in environment, researchers have focused on the use of agricultural waste [5,6] and industrial waste materials [7,8] to produce sustainable and low-cost construction materials. Some of the waste materials that have been incorporated in concrete by researchers include Waste Tire Rubber [9–11]; Nickel Slag Waste [12]; and Recycled Aggregate [13–15]. Another key approach to address sustainability and cost-effectiveness needs for construction materials is by reusing and recycling CWM. The study by Fadiya et al. [16] analysed the sources of construction waste quantitatively by exploring the contribution rates of nine identified sources of construction waste in which residual waste such as material off-cuts was recognized as the top contributor to construction waste. Their study further established that construction waste has a substantial contribution to the cost of construction. A study by Ng and Chau [17] recommended the use of a recycling strategy for building elements containing a large amount of concrete while a reuse strategy should be used for building elements with high aluminium content based on the outcomes of their study which indicated that recycling of CWM produced the highest energy saving in embodied energy (53 %) whereas the energy saving potential of reusing and incineration were 6.2% and 0.4% respectively. Bao [18] worked on developing the circularity of construction waste in emerging economies for a sustainable built environment by providing insights on implementable targeted strategies for effective construction waste management for recycling, harnessing smart technologies, economic incentives and government intervention. Another study that explored the improvement of circular economy through construction waste management advocated for the inclusion of waste management strategies in the planning process of construction projects as a holistic approach in which material, emissions and energy are considered to ensure the effective reuse and creation of recycled products from CWM [19]. A case study conducted by Saad et al. [20] revealed site management and supervision-related factors as the major sources of construction and demolition waste while waste management regulations were identified as the most critical success factors. Also, their study identified lack of law enforcement/regulation and lack of awareness/knowledge as the main barriers to implementing reducing, reusing and recycling (3R) of construction and demolition waste. Almusawi et al. [21] evaluated the status of construction and demolition (C&D) waste generation and management in Kuwait and discovered that the C&D waste from the construction sector constitutes an average of 35.4 % for concrete waste, 19.2 % for tiles/blocks, and 14.2 % for metals while other waste materials make up the remaining 31.2 %. Their study indicates that concrete waste having the largest average percentage (35.4 %) is the major waste material generated in the construction industry and efforts should be targeted on how to reuse or recycle this construction waste material. Additionally, their study identified reworks due to improper site management, inappropriate material handling, use of poor-quality material and changes in specifications as the main causes of C&D waste generation. The study on the recycling of wood–cement board manufacturing waste into a supplementary cementitious material or low-strength cementitious binder for use in building products indicated that the use of a planetary mill to grind the waste particles into smaller sizes increased the compressive strength of the samples produced with the reactivated binding material [22]. Badraddin et al. [23] explored the major challenges of concrete recycling in real life and their research findings indicate thirteen challenges to concrete recycling with the main challenges as the absence of national programs on concrete recycling, lack of all-encompassing rules/regulations, increased project duration and cost, low demand for recycled concrete increased transportation cost and, high cost of concrete recycling. Sorting of construction and demolition waste is key to ensuring the optimum reuse or recycling of these waste materials.

In the study by Huang et al. [24], the appraisal for the use of the mechanical sorting process in the recycling of construction and demolition was analysed alongside the cost-benefit analysis of the operation. The cost-benefit analysis of their study revealed that the economic potential for such a construction waste management practice could be achieved through a cost-effective recycling infrastructure program that is supported by a government subsidy program. Another study on the mechanical sorting efficiency of C&D waste established that the sorting equipment studied was able to produce nine different fractions of useful secondary materials from pre-sorted and crushed material blends [25].

Construction waste materials can be efficiently handled by reducing, reusing and recycling the waste materials [26,27]. Two key reasons for reusing and recycling CWM are environmental and economic benefits [19]. Reuse and recycling of construction waste materials have the potential of reducing the high rate of depletion of natural resources. When these waste materials are used to replace cement, they help to cut down the production of ordinary Portland cement which releases a significant amount of greenhouse gases into the atmosphere [28]. The greenhouse gases generated during cement production causes ozone layer depletion resulting in global warming and climate change. Therefore, the reuse and recycling of materials will not only boost the economy but also provide job opportunities and help in solving the global issue of environmental pollution which result in global warming. However, there have been several challenges facing the optimal reuse and effective recycling of materials generated from construction activities [23,29]. The challenges range from a lack of recycling facilities and appropriate technology to a lack of specific policies on CWM reuse and recycling [30]. Given these challenges and the negative impact of construction wastes on successful project delivery, there is need for more evidence based empirical studies to scientifically quantify the potentials, challenges and hence proffer solutions towards optimum utilization of construction waste. This study identifies the potential benefits of CWM reuse/recycling to economic development and also provides effective strategies for optimal reuse and recycling of CWM using Nigeria as case study. The reuse and recycling of CWM have the potential to reduce the depletion of natural resources, save embodied energy, save landfill spaces for wastes deposit, and protect the environment. The study offers a novel and original contribution to the existing body of knowledge on the challenges in construction waste management, as it explores the unique challenges and opportunities in the Nigerian context. Additionally, the study offers a novel viewpoint on the subject because of its emphasis on Nigeria's economic and environmental sustainability as most existing research has concentrated on developed countries. With potential applications in other developing countries, this research offers a ground-breaking framework for encouraging sustainable construction practices and reducing waste in Nigeria by identifying and addressing the barriers to the reuse and recycling of construction waste materials."

2. Review of existing knowledge in construction waste reuse and recycling

2.1. Construction infrastructure in the Nigerian economy

Practically, the development of any economy is dependent on its construction infrastructure [31,32]. In other words, what differentiates a developed economy from an underdeveloped economy is majorly the robustness of the existing construction infrastructure in such an economy. The major construction infrastructure in the Nigerian economy includes residential buildings, public buildings, roads, rail systems, airports, bridges, sea ports, water, waste management, telecommunication, and energy infrastructure. These construction projects generate tons of waste annually during their construction, deconstruction/demolition, repair and maintenance [21,33]. In the situation where these wastes are not efficiently handled, they will result in serious threats to the environment and could affect the economy adversely. An important aspect of managing CWM is the sorting/separation of the wastes into common and related clusters [34,35]. Sorting of CWM can be done manually [36], mechanically using equipment for sorting construction wastes [24] or by the use of robotics [37]. Although the use of equipment to sort CWM is more efficient, it is rarely used because it could lead to an increase in the project cost [36].

In recent years, the waste materials generated in the construction industry have been on an increasing trajectory [38]. This is due to the increasing demand for infrastructural projects as a result of the increase in the human population. The quantity of CWM in tonnes generated in selected countries is presented in Table 1. The data indicates that waste generation is not peculiar to either developing or developed economies. In other words, several tonnes of construction waste are generated from across the globe. However, countries like China with massive infrastructure generates the highest construction waste as shown in Table 1.

A review study on the analysis of the current solid waste challenges in 13 Arab countries suggests the use of the concept of circular economy in ensuring the potential of reusing huge amounts of solid waste in sustainable construction activities and indicated that extensive study of solid waste is fundamental in providing solutions to environmental and economic issues which will result in sustainable communities [29]. A study on current methods for the utilization of fresh concrete waste by Kazaz and Ulubeyli [39] presented various opportunities for the utilization of these wastes including utilization in the production of precast concrete components, use of the hardened slurry cake in partition wall blocks and blending with next concrete batches. A study on how the off-site sorting of construction waste program has been used to minimize construction waste in Hong Kong indicated that the success of the program was largely due to the Hong Kong government's good policy execution and sustaining policy support as well as the enactment of the trip-ticket system and higher disposal charges to encourage off-site construction waste sorting [34]. Another study identified the lack of government legislation and a lack of recycling facilities as the major causes of the landfilling of waste by contractors [40]. Factors influencing the generation of CWM using Thailand as a case study were identified to include four major groups which are design and documentation, material and procurement, construction method and planning, and human resources [41]. The outcome of the study which is the identification of the important factors that causes construction waste generation will assist stakeholders in the industry to develop suitable and more effective strategies for the management of construction waste. A case for sustainable construction waste management was made in a study by Nagapan, et al. [42] which highlighted the sustainable approaches to construction waste management to include adopting the waste management hierarchy and supportive legislation/policy. Another case study on a comprehensive waste management model using PESTEL and 3R for central Asia construction companies was conducted by Turkyilmaz et al. [43] it showed that the activities promoting waste reduction have the major potential of minimizing CWM when compared to reuse and recycling. A recent case study on the implementation of the CWM management practices in the construction sector in Malaysia indicated that low quality and the presence of contaminants in CWM from housing sectors gave rise to low recycling potential for the CWM [44]. A study on the possibility of using recycled concrete as normal concrete in construction applications revealed that recycled aggregate contributed to the improvement of the compressive strength of the produced concrete samples [45]. A review of the stakeholder's opinions on the use of recycled construction and demolition waste materials as well as the perceived hindrances to their utilization provided insights on the six important categories of stakeholders (civil/structural engineer, recycler, industry, architect, government, builder and client) who can influence the decision on using recycled product from CWM and how their opinions could be used for policy reform aimed at boosting the markets of CWM [46].

Table 1. Generation of construction waste materials in various countries (2016-2022).

Country	Construction waste materials generated per year (million tonnes)	References
China	2360	[47]
Germany	202.735	[48]
India	150	[49]
UK	138	[50]
Egypt	90.76	[51]
Sweden	27	[52]
Nigeria	25	[53]
Kuwait	15.74	[21]
Denmark	11.3	[52]
Malaysia	8	[54]
Tanzania	7.9	[55]
Poland	3.51	[56]
New Zealand	3.5	[56]

2.2. Concept of reuse and recycling of construction waste materials

The generation of CWM in the construction industry could be a result of errors in the design and contract documents, poor site management and supervision, procurement-related hitches, material handling problems, storage issues, poor workmanship and natural factors [57][58]. These wastes can be assembled onsite or offsite before they are sorted into their respective groups so that they can be reused, recycled or used as landfill materials. The optimized process for the utilization of construction waste materials is presented in Fig. 1.

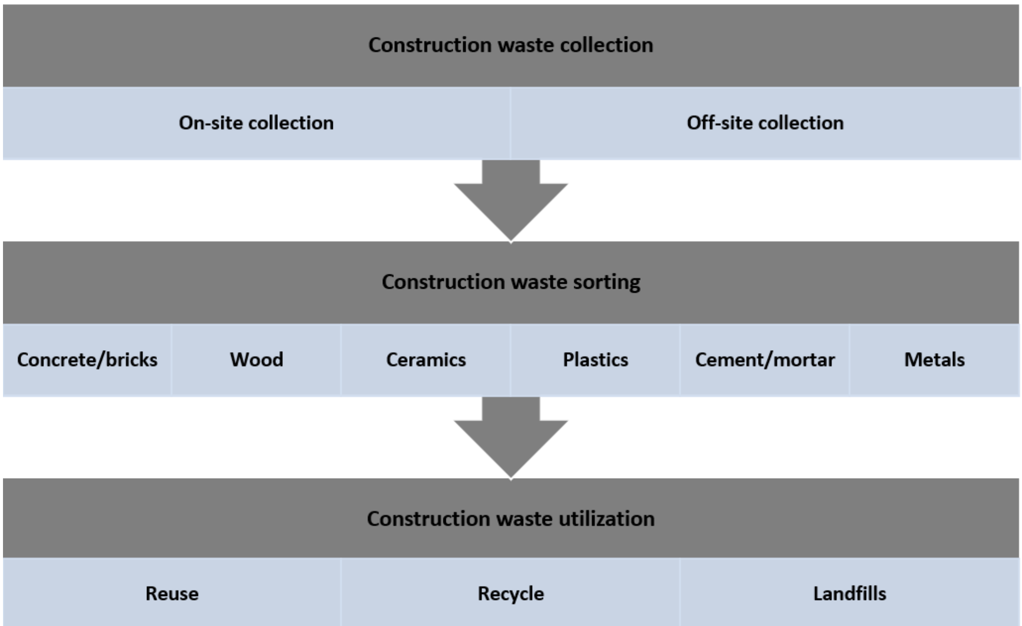

Fig. 1. Optimized process for utilization of construction waste materials.

The lack of a waste management system has resulted in the loss of useful materials which negatively impacts the national economy [59,60]. To ensure the attainment of a circular economy, every waste generated must be put to economic use either by reuse or recycling. The best way to manage CWM is to reduce its generation by preventing the situations that lead to the generation of CWM. The pyramid of how construction waste materials should be efficiently managed is presented in Fig. 2. This pyramid indicates that the most important aspect of efficient construction waste materials management is its prevention. Efforts targeted at preventing the situation that leads to the generation of large tonnes of CWM will reduce the quantity of CWM generated in the construction industry and this will ensure efficiency in the utilization of natural resources. When the generation of CWM cannot be prevented, the generated waste materials should be reused and if they cannot be reused directly, they should be recycled or recovered. When these waste materials cannot be recycled or recovered, they can be properly disposed of or used in landfills.

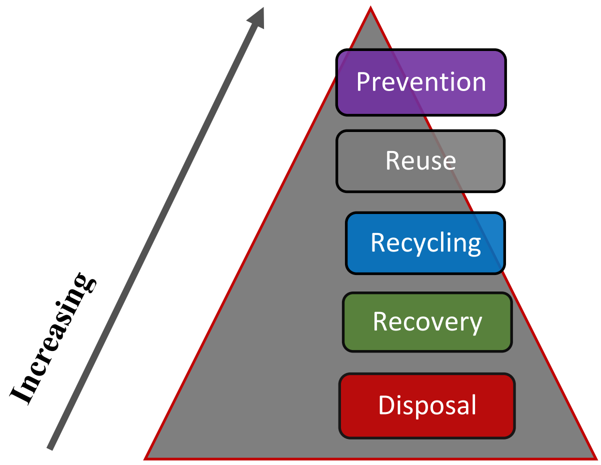

Fig. 2. Pyramid of efficient construction waste materials management.

2.3. Reusable/Recyclable construction waste materials in construction industry

Different construction materials make up the CWM and this makes it impossible for the CWM to be reused directly. Sorting and recycling of CWM are essential to improving the economic value of CWM [25]. The major classification of CWM includes cementitious, ceramics, plastics, metallic and wood materials. Sorting CWM into their respective groups improves their economic value and increases the possibility of their reuse. The grouping of CWM is presented in Fig. 3. Overview of related research works conducted on construction waste recycling and reuse is shown in Table 2.

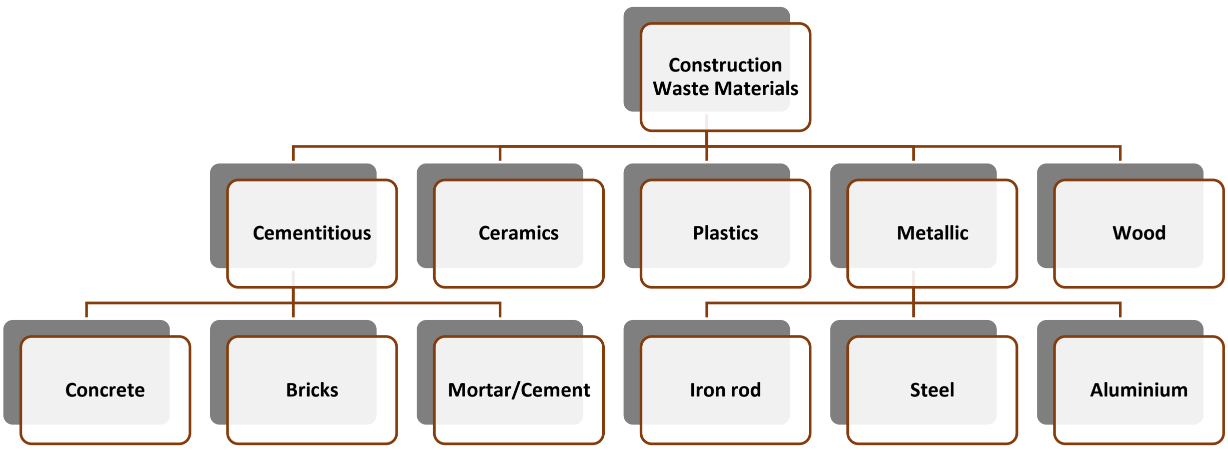

Fig. 3. Grouping of construction waste materials.

Table 2. Research conducted on construction waste recycling and reuse.

References	Focus	Methodology	Findings	Limitations
[59]	Opportunities and challenges related to waste management in India	Reports on an international seminar	India has challenges with waste legislation, choosing waste technologies, and finding qualified personnel for the waste management industry.	Focused only on India
[61]	Recycling waste from construction and demolition in developing cities: cost analysis and management	Review and Scenarios' analysis	The study concluded by showing that although CDW has very significant expenses, proper management is achievable.	The study was considered developing cities in Bolivia alone
[62]	A Comprehensive Analysis of Australia's Present Practices and Difficulties in Construction and Demolition Waste Management	Structured review and interviews	It was discovered that information relevant to Construction and Demolition Waste Management should be emphasized across the entire project lifecycle, from start to finish.	A drawback of this study and a promising area for future research would be a thorough examination of these restrictions as well as precise comparisons of Construction and Demolition Waste Management laws in Australia and other nations.
[41]	Thailand's view on the Factors affecting the generation of construction waste in building construction	literature review and structured questionnaire survey	The findings indicate that design and documentation, human resources, building methods and planning, and material and procurement are the top four categories that contribute to construction waste.	Only perspective of Thailand was considered
[49]	Case study of construction waste management in India	hypothetical model with theory of planned behaviour	The intention to adopt construction waste management is significantly influenced by three factors: attitude (0.38), knowledge (0.40), and perceived behavior control (0.52).	The study was tailored to Indian alone

Common reusable/recyclable construction waste materials include bricks/earthen materials, wood/timber, cement, concrete, iron rod, aluminium, steel, and ceramics. In the construction industry, a low quantity of plastic waste is generated. Some reusable/recyclable construction waste materials are shown in Fig. 4.

Fig. 4. Some reusable/recyclable construction waste materials.

The waste materials that can be reused or recycled in the construction industry can be derived from the following major construction materials.

Bricks/ Cement/ Gravel/ Concrete: The use of bricks/earth-based materials in construction projects reduces the carbon footprint of the projects resulting in eco-friendly and sustainable construction. Another advantage of buildings constructed with earth-based materials is the ability to reuse the materials after the demolition. Concrete is the major construction material used in the construction industry. Globally, more than 10 billion tonnes of concrete are produced every year [63]. The use of precast concrete has helped to reduce the number of concrete waste generated during project construction [64]. However, in-situ concrete (concrete produced on the construction site) is commonly used for construction projects and this generates a lot of waste during concrete pouring/casting. In other words, construction professionals hardly make use of precast slabs, beams and columns in their projects [65,66]. Cement and concrete waste materials can be reused by introducing them as fine and coarse aggregates into fresh/new concrete during production. Studies have shown that these cementitious waste materials can be effectively used in the production of fresh concrete [39,67]. However, some studies reported that the addition of these waste materials resulted in reduced strength of the produced concrete [45][68].

Wood/Timber (Windows, scaffolds and Doors): Wood/timber has been used in construction projects before the civilization of the human race [69]. In ancient times, bridges and houses are constructed with wood/timbers. The introduction of concrete has replaced the use of wood/timber in the construction of bridges. However, wood/timbers are still used as roofing trusses in building projects.

Metals (Iron, Aluminium, Steel and Roofing Materials): Metals such as iron rods are usually used as reinforcement in beams, columns and slabs for construction projects. Other metals such as aluminium and steel are used as roofing and decorative materials respectively.

Ceramics (Sanitary Wares, Glass Tiles, Marbles and Terrazzo): Ceramic wastes are generated largely due to poor workmanship. Adequate project supervision plays a critical role in reducing ceramic waste materials generated from construction projects.

2.4 Theory of sustainability and its dimensions and application in construction waste management

Sustainability can be defined as meeting the needs of the present without compromising the ability of future generations to meet their own needs [70]. The significance of striking a balance between immediate requirements and long-term sustainability is emphasized by this definition. The idea of sustainability is supported by a number of theories. According to the Triple Bottom Line (TBL) Theory, sustainability should be evaluated from three angles: economic, environmental, and social. According to this philosophy, sustainability encompasses not only environmental preservation but also the advancement of social justice and economic expansion. A comprehensive strategy is necessary to address sustainability, which is viewed as a complex system by the Systems Thinking Theory, which takes into account the interdependencies of social, economic, and environmental elements. According to this view, sustainability involves more than simply individual behavior; it also involves the interactions between other system elements.

The three main dimensions of sustainability are economic, social, and environmental. Climate change mitigation, pollution reduction, and natural resource conservation are all part of environmental sustainability. Ensuring social justice, human rights, and community well-being are all part of social sustainability. Encouraging economic development, stability, and fair resource allocation are all components of economic sustainability. The economy, society, and environment are all greatly impacted by the construction sector. As a result, using sustainable building practices is crucial. Some of the ways to achieve this include: Utilizing materials and systems that limit waste, water, and energy consumption, as well as designing and building structures with a minimal environmental impact; using recyclable, recycled, or sustainably derived materials, like salvaged wood, bamboo, and low-carbon concrete; putting in place energy-saving devices including wind turbines, solar panels, and HVAC and lighting systems; Water conservation: putting water-saving techniques into practice, like low-flow fixtures, greywater reuse, and rainwater collection; Putting waste management and reduction techniques into practice, like composting, recycling, and cutting back on trash production; maintaining healthy indoor air quality by using non-toxic materials, enough ventilation, and air filtration; and interacting with nearby communities to make sure building projects provide for their requirements and advance social sustainability.

3. Research methods

Descriptive survey design and desk study were employed in this research. A structured questionnaire comprising nine questions was used to obtain information on the reuse/recycling of CWM in Nigeria from the survey respondents. An online survey with a questionnaire designed by the researchers (see Appendix) was developed using Google forms and sent to 600 participants via social media platforms (WhatsApp, LinkedIn, and Emails) from 19th January to 20th March 2023. Purposive sampling technique was used in the study. To ensure the participation of key players in the field of study and the validity of the research results, social media platforms comprising of mainly individuals from the construction industry (Engineers/Builders and other construction professionals) were targeted during sampling. A panel of professionals with knowledge of construction waste management and recycling also examined and validated the questionnaire. Their comments and recommendations for enhancements were integrated into the final draft to guarantee the validity and reliability of the questionnaire in assessing the study variables. In order to validate the questionnaire and find any potential problems or biases, a pilot test was also carried out with a small sample of respondents. The findings indicated that the questionnaire was understandable, succinct, and straightforward, and no significant problems or concerns were raised. Responses from 438 participants out of the 600 participants were obtained. Cochran’s formula, which is appropriate in situations with large populations was used to calculate the sample size because we have large population of construction professionals in Nigeria considering Nigerian population.

The Cochran formula is:

$$n_o = \frac{Z^2 pq}{e^2} \quad (1)$$

Where: e is the desired level of precision; p is the (estimated) proportion of the population which has the attribute in question; q is 1 – p.

Assuming 20% of Nigeria population are construction Professionals. Then, p = 0.2, q= 1-0.2= 0.8. If we take 95% confidence, and at least 5 percent—plus or minus—precision, a 95 % confidence level gives us Z values of 1.96, per the normal tables, so we get

$n_o = ((1.96)^2 (0.2) (0.8)) / (0.05)^2 = 246$

This implies that a random sample of 246 construction professionals in our target population (construction professionals in Nigeria) should be enough to give us the confidence levels we need. However, a high percentage of for the probability of non-response was used considering the low return of online questionnaire. Based on this, we sent out questionnaire to 600 participants and 438 participants responded, which is higher than the expected 246 participants. This means that the error margin will be reduced due to the use of responses obtained from more than the required sample size of 246.

The questionnaire comprises five sub-headings (demographic information of the respondents; status of reuse and recycling of construction waste materials in Nigeria; challenges of optimal reuse/recycling of construction waste materials in Nigeria; strategies for best practices in the reuse and recycling of construction waste materials in Nigeria; and benefits of reuse/recycling of construction waste materials to the Nigerian economy) to provide detailed information on the reuse/recycling of CWM in Nigeria. Data obtained from the study were analyzed using descriptive analysis. Collected data from the questionnaire were analysed and plotted in charts for easy visualization and interpretation. The demographic information of the respondents indicated that 86.8 % of Engineers/Builders, 8.0 % of other construction professionals and 5.2 % of others (Academic, Engineering students and public administrators) participated in the study. The research method flow chart used for this study is presented in Fig. 5.

Fig. 5. Research method flowchart for the study.

4. Results and discussion

4.1. Benefits of reuse/recycling of construction waste materials

Efficient reuse/recycling of CWM has the potential of contributing immensely to the circular economy by ensuring construction materials are maximized, the generation of construction waste materials is prevented and the need for new construction materials is reduced. This will also contribute to the achievement of goals 11 and 13 of the sustainable development goals (SDGs) through construction waste utilization and the use of recycled CWM for different applications in building and construction projects. The key contributions of the effective utilization of CWM reuse/recycling to the circular economy are presented in Fig. 6.

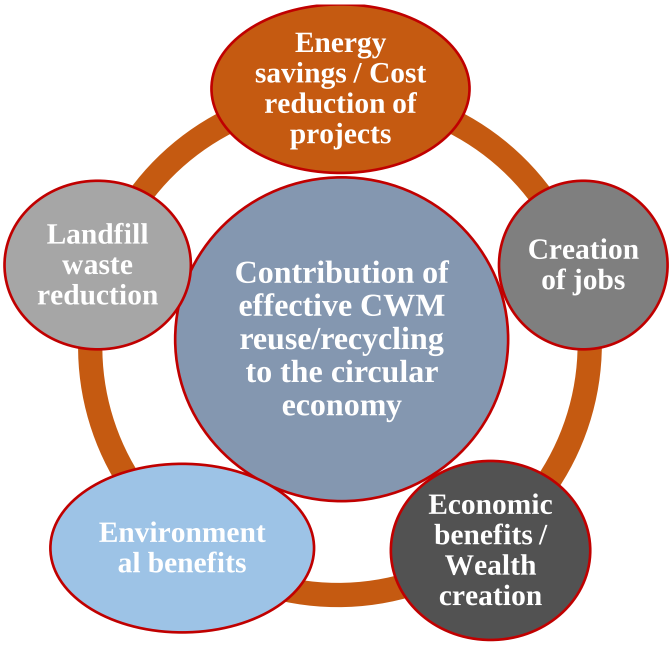

Fig. 6. Contributions of the effective utilization of CWM reuse/recycling to the circular economy.

The result of the survey conducted on the benefits of CWM reuse/recycling to the circular economy is shown in Fig. 7. Among the recognized benefits of CWM reuse/recycling, participants identified environmental and economic benefits having 43.2 % and 42.7 % respectively as the most important benefits of the reuse/recycling of construction waste materials to the Nigerian economy, followed by job creation (7.1 %), landfill waste reduction (4.1 %) and energy savings (3 %) as shown in Fig. 7. Reusing and recycling building waste can have a number of positive economic effects, such as lower waste disposal expenses, lower raw material costs, and possible income streams from the sale of recycled products. By lowering the quantity of waste dumped in landfills, conserving natural resources, and lowering greenhouse gas emissions linked to the extraction, processing, and transportation of raw materials, recycling construction waste can greatly lessen the negative environmental effects of the sector. The construction industry may minimize the damage of habitats and ecosystems, lower water pollution, and use less energy to generate new materials by recycling items like metals, concrete, and asphalt. Furthermore, by lowering the demand for virgin materials and minimizing the quantity of waste produced during the construction process, recycling construction waste can also aid in lowering the environmental effects of construction activities, such as soil contamination, noise pollution, and air pollution.

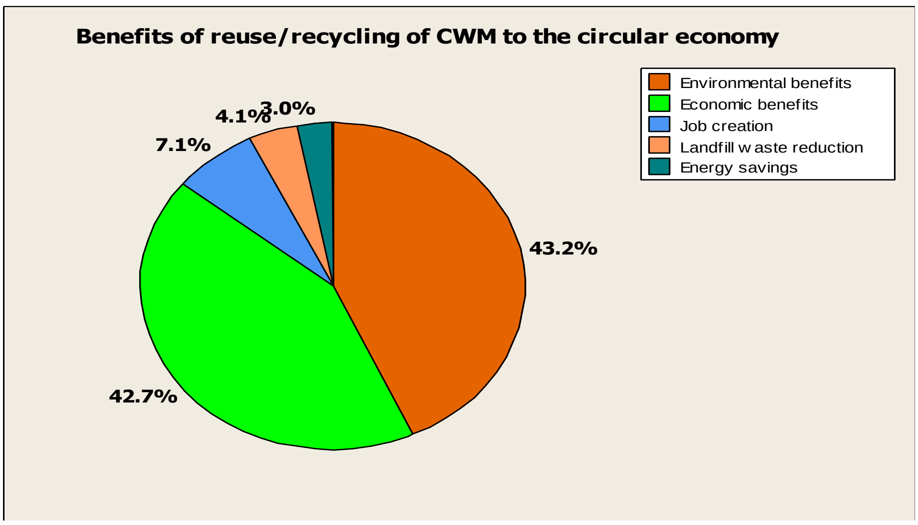

Fig. 7. Benefits of reuse/recycling of CWM to the circular economy.

Environmental benefits

Some of the CWM could cause environmental pollution when dumped in empty spaces or landfill. These toxic materials in the CWM contaminate water bodies when washed away by runoff or when they infiltrate the soil and this poses a serious threat to human life. Effective utilization of CWM will ensure a cleaner environment and will ultimately guarantee good health thereby, reducing the amount spent on healthcare issues [71].

Economic benefits

Economic benefits of reuse/recycling of CWM stem from the conversion of the waste to useful materials which can be sold to generate wealth to the reduction in the cost of construction projects through a holistic construction project planning that implements waste management strategies. A recent review and insights into the factors that various stakeholders believe influence the market for recycled construction and demolition waste products provide a reference point for authorities to consider these behavioural insights for policy reform. A study by Navarro et al. [72] revealed that the implementation of CDW management will foster the growth of a circular economy for the development of cities.

Landfill waste reduction

Most of the CWM generated in the construction industry has been dumped in landfill due to a lack of recycling plants. Despite the benefits of CWM reuse and recycling, landfilling of waste is the most common disposal method [73]. The adequate implementation of the reuse and recycling of CWM will save huge costs that will be spent on the construction of a landfill structure [74]. In addition, health issues associated with the improper management of landfills will be eliminated by reusing and recycling CWM instead of dumping them in landfills.

Energy savings

Utilization of construction waste materials is profitable in saving embodied energy that would have been used for the production of new construction materials and will as well reduce the depletion of natural resources. When CWM is reused, it reduces the cost of construction projects through materials' cost reduction and this accordance to the studies by Ng. et al. [26] and Udeaja et al. [75].

Creation of jobs

Collection, sorting and recycling of CWM have the potential of reducing the unemployment rate in Nigeria through the addition of new streams of jobs. According to the analysis by Ayeleru, et al. [76], about 677 potential jobs could be created on waste recycling facility projects in Soweto, South Africa. The potential of job creation via the reuse and recycling of CWM could only be achieved through the establishment of adequate recycling plants in Nigeria.

4.2. Challenges of optimal reuse/recycling of construction waste materials in construction

Construction waste recycling presents several obstacles, such as material contamination, a lack of uniformity, and high processing costs, all of which can make it challenging to create recyclable materials of good quality. The adoption of cutting-edge sorting technology, the formulation of novel recycling guidelines, and the establishment of financial incentives for builders and contractors to give recycling and material reuse first priority are some possible answers to these problems. Additionally, raising stakeholders' knowledge and educating them about the advantages and significance of recycling construction waste can spur innovation and investment in this field. In the end, this will increase the quantity of waste that is recycled and reused, lessening the environmental effects of the construction sector.

Four factors were listed in the questionnaire as the hindrances to the optimal reuse/recycling of CWM in Nigeria and they include lack of recycling facilities, poor waste separation practices, lack of appropriate technologies, and lack of specific government policy on reuse and recycling of construction waste materials. The potential reason for the lack of recycling facilities for CWM could be the cost of establishing such facilities. Establishing a recycling plant/facility cost as high as USD$ 1886865.70 [76].

In developing countries like Nigeria, the development of appropriate technologies for CWM recycling is still far-fetched. The existing recycling technologies in developed countries have proven that recycling CWM is viable and sustainable. Waste handling of CWM requires manpower and techniques to achieve optimum utilization of the waste materials. This is because the waste materials generated from construction sites are usually a combination of materials such as cement, wood, concrete, iron bars, plastics and ceramics. Unfortunately, there is a lack of proper waste separation techniques/practices. Agricultural and household wastes have received government attention in terms of policy formulations and enforcement [77]. However, there is no government policy on CWM or task force ensuring that construction companies manage their CWM appropriately. Among these identified challenges, the lack of recycling facilities having a score of 83.8 % was identified as the biggest hindrance to the optimal reuse/recycling of construction waste materials in Nigeria, followed by the lack of appropriate reuse/recycling technology (6.4 %), poor waste separation/sorting practices (5.7 %), and lack of specific government policy (4.1 %) as presented in Fig. 8.

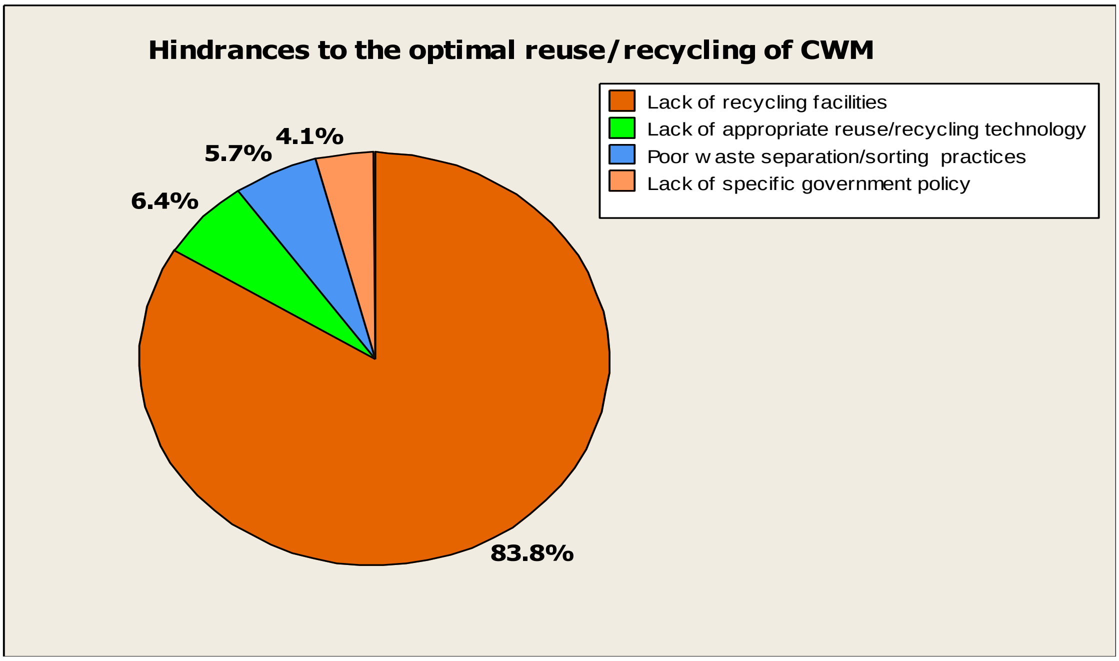

Fig. 8. Hindrances to the optimal reuse/recycling of CWM in Nigeria.

4.3. Strategies for best practices in reuse and recycling of construction waste materials

The role of different arms of government in the reuse and recycling of CWM especially in the areas of policy formulations and implementations of strategies is critical to achieving the optimal reuse and recycling of CWM. To understand the critical area of focus for implementing the strategies for optimal reuse and recycling of CWM, basic studies on the status of reuse and recycling of construction waste materials in Nigeria were conducted and they are presented in Fig. 9. Participants were tested on their knowledge of the existence of construction waste material recycling plants in Nigeria. The result shows that only 90.2 % of the participants knew of construction waste material recycling plants in Nigeria whereas 9.8 % do not know of the existence of such facilities in Nigeria as shown in Fig. 9a. This implies that there is a need to establish more construction waste material recycling plants in Nigeria and this was confirmed by the result obtained when the participants were asked if they think Nigeria has adequate construction waste material recycling plant. Only 2.7 % of the participants answered in affirmation whereas 97.3 % believe that Nigeria is in deficiency of construction waste material recycling plants as presented in Fig. 9b. Six construction waste materials (see Appendix) were identified and the participants were asked to select the most reused/recycled construction waste material in Nigeria. Steel/iron bar having 83.5 % was identified as the most reused/recycled construction waste material followed by concrete and wood having 6.4 % and 4.6 % respectively whereas plastics and cement/mortar scored 4.6 % and 0.7 % respectively as shown in Fig. 9c. Participants were further asked the extent they think that construction waste materials are reused/recycled in Nigeria. The majority of the survey participants (94.1 %)(c) indicated that less than 20 % of construction waste materials are reused/recycled in Nigeria while 3.7% and 2.1 % of the participants went for more than 20% and more than 50 % as presented in Fig. 9d.

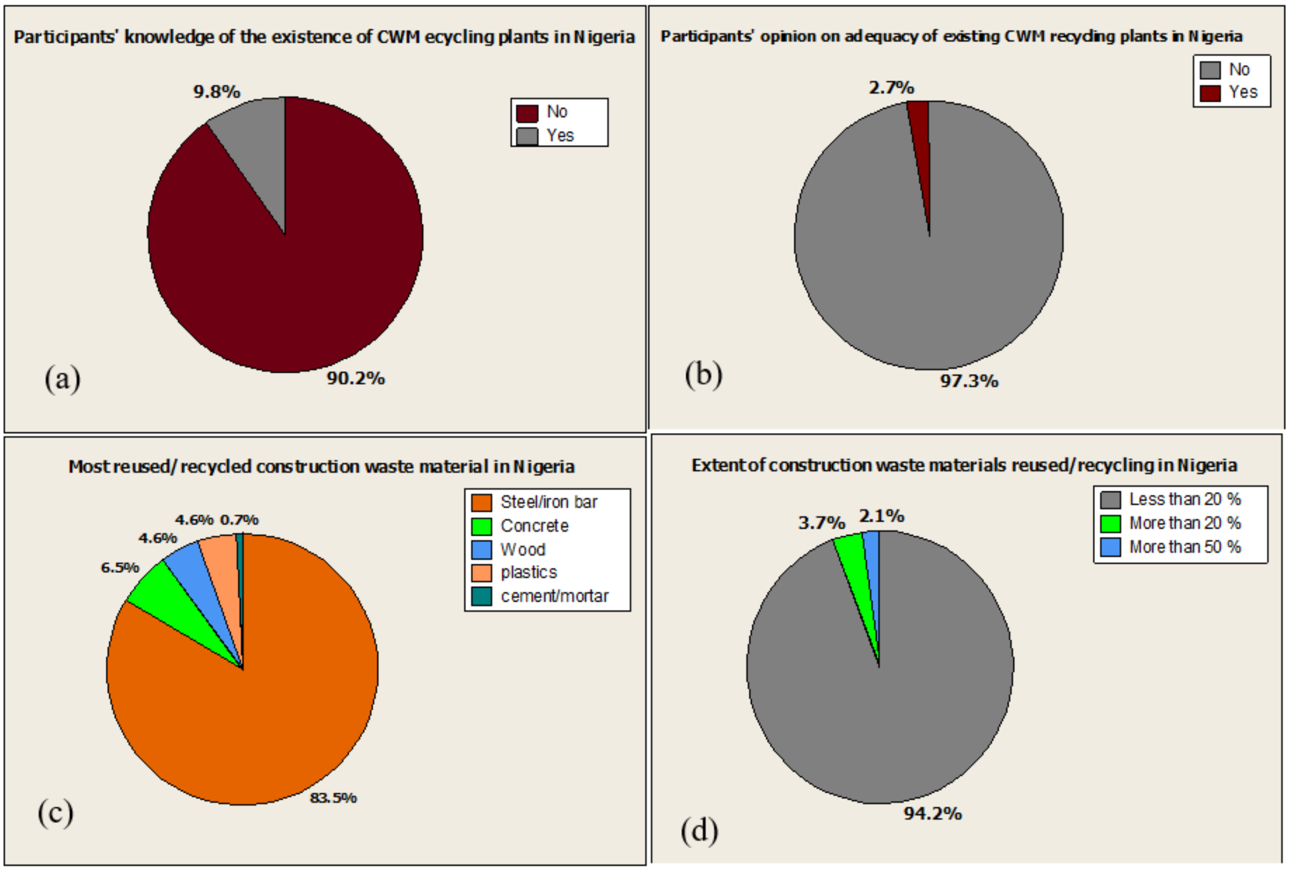

Fig.

Fig. 9. Status of reuse and recycling of construction waste materials in Nigeria.

The questionnaire used in this study identified six strategies to engage for optimal reuse and recycling of CWM. The strategies are waste recycling policy and regulations, holistic construction project planning, the establishment of local recycling centres, investing in research and development, good waste separation/soring practices and government incentives. To reduce the quantity of CWM that goes to landfills, targeted policies on waste recycling must be formulated by the stakeholders which comprise construction industries, research institutions and the government. Government agencies that are responsible for enforcing the formulated policies should be empowered to enable them to perform their duties efficiently. All-inclusive construction project planning is key to achieving effective reuse and recycling of CWM. This entails factoring in CWM reuse and recycling during the construction project planning stage. Construction waste materials' economic value could be improved by implementing proper waste separation techniques/practices. Incentives to the construction industry and the individual who recycle waste materials. Government incentives on CWM reuse/recycling can increase the effective reuse/recycling of CWM and will result in ensuring a circular economy. Among the recognized strategies, is the establishment of local recycling centres having a score of 77.1 % was identified as the most effective strategy for solving the challenges of optimal reuse/recycling of construction waste materials, followed by holistic construction project planning (6.8 %), waste recycling policy and regulation (5.5 %), good waste separation/soring practices (3.9 %), government incentives (3.7 %) and investing in research and development (3.0 %) as shown in Fig. 10.

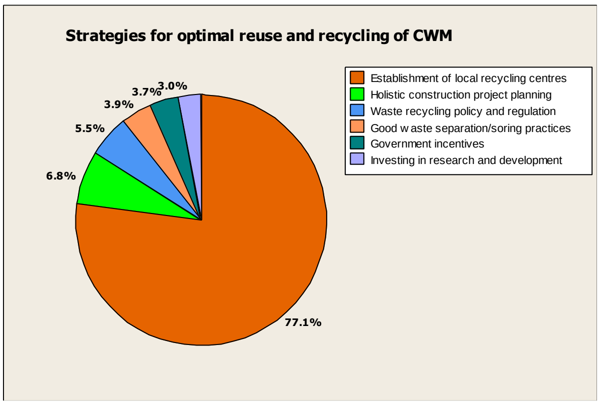

Fig. 10. Strategies for optimal reuse and recycling of CWM in Nigeria.

4.4. Policy implications and recommendations

Based on the challenges of optimal reuse/recycling of CWM articulated in this study and the effective strategies provided for CWM optimal utilization, the establishment of local recycling plants in 776 local government areas in Nigeria will help to harness the enormous economic benefits of reuse/recycling of CWM. This study highly recommends the need for the government to partner with the private sector to ensure the timely establishment of local recycling centres in all local government areas through provision of incentives in form of soft loans to waste recycling start-ups as well as grants to organizations/research institutions through funding agencies such as TETFund. Additionally, holistic construction project planning including construction waste management plans should be employed to ensure the reduction of waste materials generated by construction industries. Waste recycling policies/regulations and government incentives are necessary to stimulate the optimum reuse/recycling of CWM by stakeholders in the construction industry. Strengthening the institutions of government will enable them to function optimally in ensuring the implementation of waste recycling policies/regulations. The Legislative arm of government is mandated to make good laws and policies for optimal reuse/recycling of CWM whereas the Executive is required to review and approve the formulated laws and policies while the Judiciary is tasked to ensure the implementation of the formulated laws and policies on reuse/recycling of CWM by giving punishments to offenders. An overview study of the present situation in the reuse/recycling of CWM in Nigeria gave the results presented in Fig. 11. Seven groups of players were recognized in the questionnaire and the participants were asked to identify which one among these groups has the highest responsibility in ensuring the optimal reuse/recycling of CWM in Nigeria. Three major key players were identified by the results of the survey questionnaire with government and government agencies/parastatals (76. 5 %) as the group that has the highest responsibility in ensuring the optimal reuse/recycling of CWM, followed by construction companies (14.4 %) and individuals (5.9 %) as presented in Fig. 10. Other key players that were identified include professional bodies – NSE (Nigerian Society of Engineers), NICE (Nigerian Institute of Civil Engineers) and CORBON (Council of Registered Builders of Nigeria) with a score of 1.8 % and research institutions (1.4 %). The government (Ministry of Works and Housing at the federal and state levels) should enforce policies and regulations targeted at ensuring the optimal reuse and recycling of CWM as well as provide incentives such as soft loans to recycling start-up companies and grants to research institutions. Private construction companies such as Julius Begger should promote the

3R (recycle, reuse and recovery) during project planning and execution. The use of recycling is recommended for the building elements containing large amount of concrete whereas reusing is best for the building parts with high aluminum content [17]. R&D organizations such as Universities and NBRRI should engaged in research works aimed at improving the values and strength of CWM to promote the use of CWM in diverse kind of projects. Professional bodies such as COREN (Council for the Regulation of Engineering in Nigeria), CORBON and NSE should ensure materials' standardization by developing codes and standards for CWM use in construction projects which will also promote its acceptability and use in the construction industry.

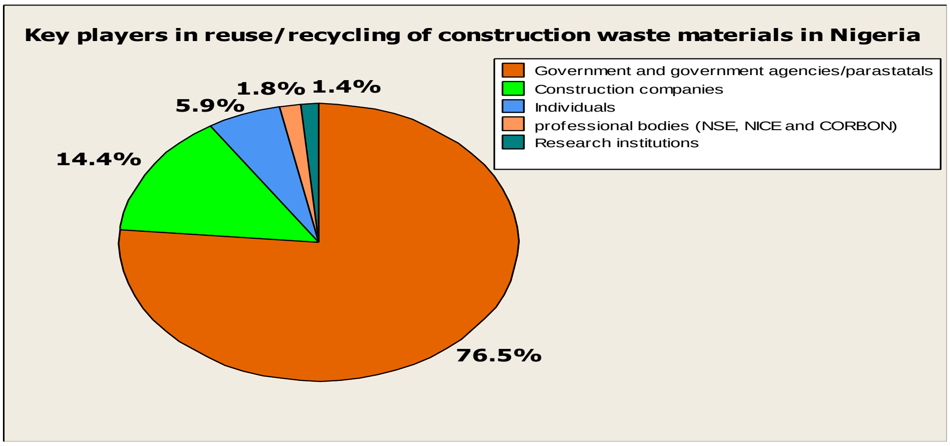

Fig. 11. Key players in the reuse/recycling of construction waste materials in Nigeria.

A working guide is necessary for the formulation of effective laws and policies on the optimal reuse/recycling of CWM. This study provides a simple model to follow in the formulation of functional laws and policies on the optimal reuse/recycling of CWM as shown in Fig. 12. A reference point such as economies or countries that have developed successful laws and policies on the optimal reuse/recycling of CWM should be studied and adapted to suit the Nigerian system. The modified laws and policies need to be standardized to align with both local and international standards. The standardized laws and policies will then be optimized foreffective implementation to maximize the benefits of the formulated laws and policies.

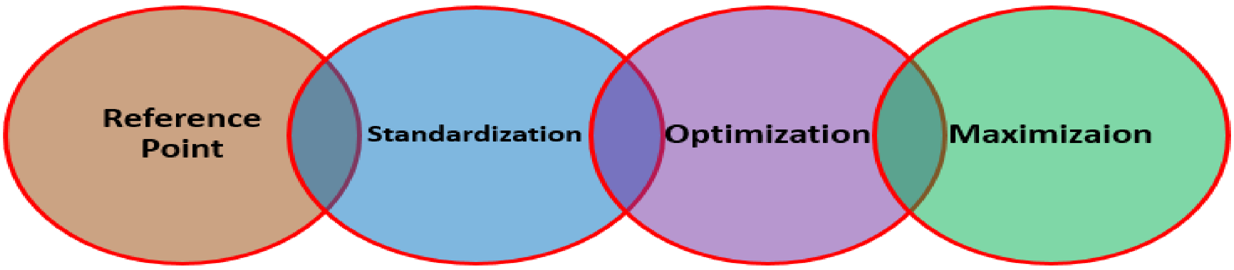

Fig. 12. Working guide for formulation and implementation of policy on reuse/recycling of construction waste materials.

One of the drawbacks of recycling construction waste is that survey responses may contain biases due to contractors and builders overstating or understating their recycling rates, which could result in erroneous assessments of how effective recycling initiatives are. Furthermore, because recycling infrastructure, laws, and cultural perspectives on waste management can differ greatly between nations and regions, the study's particular context and location may have limited the findings' ability to be applied generally to recycling construction waste. Additionally, it may be difficult to compare results from various studies due to the absence of standardized techniques for calculating and disclosing construction waste recycling rates. This makes it difficult to pinpoint best practices and create practical plans for raising recycling rate.

5. Conclusions

Reuse and recycling of CWM in construction have a key role to play in the recovery and improvement of Nigeria's economy. When CWM is reused or recycled, not only economic values are added to the economy but environmental issues are also tackled. Recycling CWM results in turning waste into wealth and preventing global warming caused by producing new construction materials and the environmental pollution from the CWM. The following conclusions were drawn from the study:

- Environmental and economic benefits having 43.2 % and 42.7 % respectively were identified as the main important benefits of the reuse/recycling of construction waste materials.
- Among these identified challenges, the lack of recycling facilities having a score of 83.8 % was identified as the biggest hindrance to the optimal reuse/recycling of construction waste materials in Nigeria. This implies that to efficiently reuse and recycle CWM, the challenges facing the recycling of these waste materials have to be eradicated.
- Establishment of local recycling centres having a score of 77.1 % was identified as the most effective strategy for solving the challenges of optimal reuse/recycling of construction waste materials. Based on these findings, efforts should be targeted at establishing construction waste recycling facilities in the 776 local government areas of Nigeria.
- Government/government agencies or parastatals having the score of 76. 5 % was identified as the major key players with the highest responsibility in ensuring the optimal reuse/recycling of CWM. This implies that effective government policies on CWM reuse and recycling together with holistic construction project planning that implement waste management techniques will contribute immensely to the revamping of the Nigerian economy. Also, a working guide for formulation and implementation of policy on reuse/recycling of construction waste materials moving from reference point to standardization and then to optimization and maximization is proposed.

The findings of this study have significant implications for the creation of practical solutions to Nigeria's challenges with the reuse and recycling of construction waste materials. By implementing these strategies, Nigeria can reduce its dependency on virgin materials, foster a culture of sustainability, and generate new business opportunities and jobs in the construction industry—all of which will help the country meet the Sustainable Development Goals (SDGs) of the UN. A cost-benefit analysis of recycling construction waste will be conducted in future research to strengthen the campaign for recycling. The future research will involve quantifying the economic benefits of recycling construction waste.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors contribution statement

Ifeyinwa Obianyo: Conceptualization; Methodology; Investigation; Formal analysis; Writing original draft.

Azikiwe Peter Onwualu: Conceptualization; Methodology; Supervision; review & editing.

Assia Aboubakar Mahamat: review & editing; Data curation; Validation.

Esther Nneka Anosike-Francis: Review & editing; Validation.

Sylvia Echezona Kelechi: Review & editing; Validation.

Emmanuel Onche: Review & editing.

Appendix

QUESTIONNAIRE

Research Topic: Potential Benefits of Construction Waste Materials Reuse and Recycling to the Nigerian Economy

Sustainability of building materials requires minimal or no waste which entails the reuse and recycling of construction waste materials (CWM). In developing economies such as the Nigerian economy, there is a need to encourage the reuse and recycling of CWM to improve the economy. This study is aimed at identifying the potential of construction waste materials reuse and recycling in the Nigerian economy.

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A. Demographic Information of the Respondents

1. **Occupation:** Engineers/Builders Other construction professionals ☐ Academic Others ☐

B. Status of reuse and recycling of construction waste materials in Nigeria

1. **Do you know any construction waste material recycling plants in Nigeria?** Yes No
2. **Do you think Nigeria has adequate construction waste material recycling plant?** Yes No
3. **Which construction waste material do you think is most reused/recycled in Nigeria?**
   a. Concrete
   b. Wood
   c. Ceramics
   d. Plastics
   e. Cement or mortar
   f. Steel or iron
   g. Others (Specify): ……………………………………………………………..
4. **To what extent do you think that construction waste materials are reused/recycled in Nigeria?**
   a. Less than 20 %
   b. More than 20 %
   c. More than 50 %
   d. More than 75 %

C. Challenges of optimal reuse/recycling of construction waste materials in Nigeria

1. **Which among these challenges is the biggest hindrance to the optimal reuse/recycling of construction waste materials in Nigeria?**
   a) Lack of recycling facilities
   b) Poor waste separation/sorting practices
   c) Lack of specific government policy
   d) Lack of appropriate reuse/recycling technology

e) Others (Specify): ……………………………………………………………..

D. Strategies for best practices in the reuse and recycling of construction waste materials in Nigeria

1. Which among these strategies is the most effective strategy for solving the challenges of optimal reuse/recycling of construction waste materials?

a. Establishment of Local Recycling Centres
b. Waste Recycling Policy and Regulations
c. Investing in Research and Development
d. Holistic Construction Project Planning
e. Government incentives
f. Good waste separation/sorting practices
g. Others (Specify): …………………………………………………

2. Who among these groups has the highest responsibility in ensuring the optimal reuse/recycling of construction waste materials in Nigeria?

a. Government and Government Agencies/Parastatals
b. Individuals
c. Financial institutions
d. Non-governmental organizations
e. Construction Companies
f. Research Institutions
g. Professional Bodies (NSE, NICE, CORBON)
h. Others (Specify): ……………………………………………………………

E. Benefits of reuse/recycling of construction waste materials to the Nigerian economy

1. Which among these benefits is the most crucial benefit of the reuse/recycling of construction waste materials to the Nigerian economy?

a. Environmental benefits
b. Economic benefits
c. Energy savings
d. Landfill waste reduction
e. Creation of jobs
f. Others (Specify): …………

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