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Eco-friendly Recycled Concrete Aggregate (RCA) and its Potential Use in Construction Projects

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ABSTRACT

Naturally occurring stone deposits are being rapidly depleted due to the exploitation of resources. Consequently, using recycled concrete aggregate (RCA) for construction works could be a sustainable alternative to promoting circularity in construction. Thus, the study assesses the extent of RCA usage in construction projects, intending to enhance sustainability through circular economy strategies by assessing the solid waste materials found in RCA, evaluating the factors driving the usage of RCA, and determining the extent of RCA usage in construction project delivery. The study employed a cross-sectional research design to collect data in one session. Construction professionals with prior RCA experience constitute the study's population. The study adopts a multi-sampling technique where the snowball and purposive sampling methods were used to select 161 construction practitioners in Lagos Metropolis. The statistical tools deployed for analysis comprised frequency, percentage, mean score, relative importance index, percentage mean utilization, and ranking. Findings revealed that RCA is mostly employed for hardcore filling in foundation construction. Besides, RCA is barely utilized in 4.8% of construction projects. The study concludes that the current level of RCA usage for construction works falls short of its full potential. This implies that RCA is underutilized in construction, resulting in the continued depletion of natural resources. Therefore, the study recommends that construction practitioners employ RCA in areas where they are not engaged to optimize RCA eco-friendliness through circular economy strategies. This may be accomplished by specifying the material for construction works and developing the requisite technology to unlock its potential fully.

INTRODUCTION

The construction sector is a key driver of economic progress and infrastructural development (Simeon & Soyingbe, 2023). Yet, the construction sector consumes an enormous amount of energy and contributes to the global release of greenhouse gases through its operations. Udawatta et al. (2015) buttressed that the industry negatively impacts the environment. This implies that construction operations typically have a detrimental influence on the environment in the form of waste. As such, the construction industry generates significant amounts of waste due to construction and demolition (C&D) activities. Li et al. (2020) opine that C&D waste accounts for 30-40% of all solid waste. The high percentage poses significant environmental issues to the environment, including pollution, among other issues (Bakchan et al., 2019). Besides, improper disposal of concrete waste can have negative environmental consequences (Badraddin et al., 2021; Asnor et al., 2022). Thus, sustainable waste management techniques are crucial in light of the escalating ecological issues. Accordingly, Luangcharoenrat et al. (2019) and Islam et al. (2019) opine that recycling concrete is essential for minimizing the negative environmental effects of concrete waste. Recycling C&D waste is one viable path, especially when developing new concrete manufacturing techniques.

The trend of using recyclable materials in construction is expanding due to increased resource scarcity and rising material costs. Besides, growing environmental concerns have pushed the construction sector into seeking more environmentally friendly options. One such eco-friendly substitute is recycled concrete aggregate (RCA), which is often regarded as recycled concrete (RC). Crushed concrete from old or demolished buildings, otherwise regarded as RCA, is used as aggregate in freshly mixed concrete to produce recycled aggregate concrete (RAC) products. Aggregates, commonly known as crushed stones, are inert materials used in making concrete and constitute approximately 70-75% of the overall volume of the concrete mass. Furthermore, the qualities of concrete are heavily influenced by the properties of the aggregates used to make it.

According to Verian et al. (2018), recycled aggregate may be obtained from existing concrete, thus termed RCA. Wijayasundara et al. (2018) and Tam et al. (2018) opine that the use of RCA in place of virgin aggregate has received attention most lately. Silva et al. (2015) and Oladiran et al. (2020) buttressed that the conventional approach for manufacturing concrete consumes a lot of virgin aggregates, which greatly depletes resources and degrades the environment. On the contrary, recycling C&D waste is a step towards circularity and provides a sustainable replacement, minimizing the strain on landfills and the need for natural resources (Xing et al., 2022; Badraddin et al., 2022). Moreover, studies (Yeheyis et al., 2013; Udawatta et al., 2015; Ugural et al., 2020) have demonstrated the beneficial effects of recycling concrete wastes, which may be broadly categorized as social, economic, and environmental benefits. Natural aggregate (NA) consumption in Nigeria has increased noticeably due to the growing need for building and infrastructure projects. RCA may be used in construction due to its economic and environmental benefits.

More specifically, RCA lessens the need for NA, reduces waste deposited in landfills, and lowers the carbon impact of manufacturing and transporting NA aggregates. Nonetheless, the application of RCA in construction projects is limited as a result of several concerns regarding its resilience, mechanical properties, and reaction under various exposure conditions. Ramadevi & Chitra (2017) reckoned that the main weakness of RCA remains concerns about enhancing its mechanical properties and durability. Besides, De Brito et al. (2012) note that early use of RAC showed less durability, increased creep and shrinkage, and weaker strengths than natural aggregate concrete. Further studies have revealed that maintaining the quality of the original concrete, completely recycling and cleaning the aggregate, designing the mix correctly, and curing the RAC all improve the mechanical qualities of concrete (Tayeh et al., 2020). Certain durability concerns, including a greater rate of carbonization, nonetheless, still exist (Guo et al., 2018). Since RAC has a larger porosity than NA concrete, it has less frost resistance. As a result, there are concrete applications (such as in structures exposed to harsh environments) where RCA cannot completely replace NA (Zaharieva et al., 2004).

Moreover, further studies indicate that RCA frequently has higher water absorption, increased porosity, and lower compressive strength. These characteristics might harm the overall performance of concrete composed of these materials (Zaharieva & Dimitrov, 2023; Sadowska-Buraczewska et al., 2020). Reduced mechanical characteristics result from a weakened interfacial transition zone between the crushed stone and the cement matrix caused by adherent mortars on recycled aggregates [24] (Kim et al., 2023). Due to the potential for quality decline, RCA may only be used in low-strength structures (Noshin et al., 2022). Additionally, there are difficulties in attaining consistent results in concrete mixtures because of the diversity in RCA quality, which might vary depending on its source and processing techniques (Gonçalves & Brito, 2010). Thus, these issues stem from RCA's composition, which commonly includes pollutants that might lower the quality of fresh concrete, including organic materials, residues of the old cement paste, and other impurities. These concerns and many more limit RCA's applications in construction projects. To this end, the problem that this study attempts to address is providing a sustainable alternative to the negative effects of construction activities on the environment.

The study aims to assess RCA's usage in construction projects with a view to enhancing sustainability through circular economy strategies. The objectives of the study are to assess the solid waste materials that are found in RCA, evaluate the factors driving the application of RCA, and determine the extent of RCA usage on potential areas of application in construction project delivery. The study is significant because it promotes sustainable construction strategies while addressing crucial environmental concerns.

MATERIALS AND METHODS

The study adopts a cross-sectional research design to collect data from the respondents on a one-off basis, as in the studies of Simeon et al. (2023a) and Lagos State, Nigeria Served as the study area. Lagos State was selected because it is the leading generator of recycled concrete aggregate, which is derived from construction and demolition (C&D) waste materials generated when a building or road is commissioned for development. The study was conducted in the metropolitan areas of Lagos State, which comprises 16 local government areas. The main features of the local government areas in the metropolis where the study was carried out are that they are built-up areas with existing buildings and access roadways.

In these locations, old existing properties are either being redeveloped by the previous owners or sold to developers. Most developers who purchase these properties do so intending to demolish the older buildings and rebuild them with more modern ones. Besides, massive infrastructural development works are ongoing across Lagos metropolitan areas by the State Government in line with the present governor's THEMES+ Agenda. Therefore, existing, worn paved roads (asphalt, concrete, paving stones, etc.) are phased off the roadways, and old drainages are demolished and carted away to allow for the construction of new ones. These characteristics made Lagos State an ideal location for conducting this research. The study population comprised key built environment practitioners (Architects, Builders, Engineers, and Quantity Surveyors) who are knowledgeable about the usage of RCA and have utilized it at one point or the other on building and infrastructural projects. The absence of an updated list of practicing construction professionals who are knowledgeable on the use of RCA and have utilized it for various applications in construction projects enabled the researchers to rely on multi-sampling techniques to select 161 users of RCA.

The two methods of selection are snowballing and purposive sampling strategies. According to Simeon & Oladiran (2023), the snowball sampling strategy is adopted in an unfamiliar and rare population, and study participants are asked to help identify known possible responses. Researchers using the purposive sampling approach select the units to be included within the samples using a good judgment strategy (Umeh, 2018). The primary data was collected through a structured close-ended questionnaire instrument. The structured questionnaire instrument that was designed for the study was divided into 4 sections. Section A collected information on the demographic characteristics of the respondents. Section B assesses the levels of familiarity of the respondents with 14 solid waste materials commonly found in RCA using a Likert scale of 1-5. Where 1 indicates not familiar, 2 indicates slightly familiar, 3 indicates moderately familiar, 4 indicates familiar, and 5 indicates very familiar. Meanwhile, Section C evaluates 18 important factors driving the use of RCA for project delivery using a Likert scale of 1-5. Where 1 indicates not important, 2 indicates slightly important, 3 indicates moderately important, 4 indicates important, and 5 indicates highly important.

Moreover, Section D of the study determined the extent of usage of RCA in 24 potential areas of application in construction projects. Participants rated each project on a scale of 1-10, identifying areas where RCA was applied in the past five years. A total of 250 copies of questionnaires were self-administered to the targeted respondents after 8 weeks, out of which 185 were returned. The returned questionnaires were checked for errors and completeness. At the end, 161 questionnaires were deemed valid for inclusion in the analysis, representing a 64.4% response rate. This is a good response rate considering the low response rates usually encountered in getting construction professionals to fill out survey questionnaires. The collected data were processed with Microsoft Excel 2021 and the Statistical Packages for the Social Sciences (SPSS, V. 26.0). The statistical tools deployed for the analyses comprise frequency, percentage, mean score, relative importance index, percentage mean application (%MA), and ranking. Moreover, reliability tests were conducted and revealed that the Cronbach's Alpha values of sections B and C gave an average of 0.947, indicating "excellent".

Objective 1, which seeks to assess the level of familiarity of solid waste materials commonly found in RCA, was analyzed using the mean scores equation as displayed in equation 1.

$$MS = \frac{\Sigma X}{N} \quad [1]$$

Where: MS denotes the mean score; ΣX is the summation of all scores or values; N denotes the total number of all items in the group.

Objective 2, which seeks to evaluate the factors driving the use of RCA in construction project delivery, was analyzed using the relative importance index equation (RII) as displayed in equation 2.

$$RII = \frac{\Sigma w}{A \times N} \quad [2]$$

Where RII denotes the relative importance index, W denotes the weight assigned to each factor by the participants, which ranges between 1-5; A denotes the highest weight =5; N denotes the total number of participants. The RII score ranges from 0 to 1. Each factor's value indicates its level of application.

Objective 3, which seeks to establish the level of use of RCA for the manufacturing of different applications of recycled aggregate concrete (RAC) products, was analyzed using Microsoft Excel (2021) formulas.

The formulas are expressed in the equations below.

PMU of RCA on each RAC product =

$$\frac{\text{No of times RCA was applied for producing RAC product}}{\text{Total number of time RCA was applied}} \times 100\% \quad [3]$$

Where PMU denotes the Percentage Mean Utilization.

Additionally,

$$\text{The total mean utilization of RCA} = \frac{D}{C} \quad [4]$$

Where:

C = total number of possible uses of RCA by respondents on projects

D = total number of projects where RCA was used.

Moreover:

$$\% \text{ MU of RCA} = \frac{\text{Total no. of projects where RCA was used}}{\text{Total no. of times RCA was applied}} \times 100\% \quad [5]$$

Where: % MU denotes the percentage mean utilization of RCA.

It is essential to recognize and abide by the ethics governing this type of study. In doing so, the authors upheld and preserved the rights of people, animals, and places without abdicating their particular obligations. As a result, the investigation was carried out impartially and with due diligence to ensure that all possible hazards were eliminated. The participants understood their rights. The right to secrecy, informed permission, anonymity, and respect for individuals are among the ethical concerns of this study. However, the relevant organizations gave authorization for this research to be conducted therein.

RESULTS AND DISCUSSION

Demographic Profile of the Respondents

Table 1 displays the demographic profile of the respondents and organization characteristics. Table 1 reveals the profession of the respondents, and it can be seen that 29.2% of the respondents are architects, 32.9% are builders, 26.7% are civil engineers, and 11.2% are quantity surveyors. Table 1 also shows the highest academic qualifications of the respondents. As displayed, 1.9% of the respondents have National Diploma Certificates, 23.6% have Higher National Diploma Certificates, 48.4% have Bachelor's degrees, 6.8% have Post Graduate Diploma Certificates,16.8% have Master's degrees, while 2.5% have Doctorate. Table 1 also shows the distribution of the respondents' years of experience. About 31.1% of the respondents have 0-5 years of experience, 26.7% of respondents have 6-10years of experience, 19.3% of respondents have 11-15years, 14.3% of respondents have 16-20 years of experience, and 8.7% have above 20 years of work and business experience. Regarding the respondents' affiliations with their respective professional associations, about 29.2% of the sampled respondents are affiliated with the Nigerian Institute of Architects (NIA), 32.9% are affiliated with the Nigerian Institute of Building (NIOB), 26.7% are affiliated with the Nigerian Society of Engineers (NSE), and 11.2% of the respondents are affiliated to Nigerian Institute of Quantity Surveyors. In terms of the respondents' organization sizes, a vast majority (90.9%) of the construction organizations surveyed are micro-small-medium-sized, while only 9.1% work in large-sized construction organizations. This implies that MSMEs are more receptive to employing RCA for construction works. Regarding the ownership of these organizations, 65.8% of the organizations are indigenously owned, 14.3% are owned by expatriates, and 19.9% are partly owned by indigenous and expatriate firms. Since the study focuses on RAC adoption in Nigeria, a significant number of fully indigenous respondents is essential since it necessitates an indigenous viewpoint. In terms of the organizations' nature of work carried out, 74.5% of the firms render building construction works, while 25.5% are into road projects.

Table 1. Demographics Profile of the Respondents'

Description	Frequency (N)	Percentage (%)
Profession		
Architect	47	29.2
Builder	53	32.9
Civil Engineer	43	26.7
Quantity Surveyor	18	11.2
Total	161	100.0
Highest Academic Qualification		
Ordinary National Diploma (OND)	3	1.9
Higher National Diploma (HND)	38	23.6
Bachelor of Science (B.Sc.)	78	48.4
Post Graduate Diploma (PGD)	11	6.8
Master of Science (M.Sc.)	27	16.8
Doctorate (PhD)	4	2.5
Total	161	100.0
Year of Experience		
0 – 5 years	50	31.1
6 – 10 years	43	26.7
11 – 15 years	31	19.3
16 – 20 years	23	14.3
21 and above years	14	8.7
Total	161	100.0
Professional Affiliation		
NIA	47	29.2
NIOB	53	32.9
NSE	43	26.7
NIQS	18	11.2
Total	161	100.0

Organization Size		
Micro (1-9)	50	31.1
Small (10-49)	63	39.1
Medium (50-250)	33	20.5
Large (above 250)	15	9.3
Total	161	100.0
Ownership		
Fully Indigenous	106	65.8
Fully Expatriate	23	14.3
Partly Indigenous/Partly Expatriate	32	19.9
Total	161	100.0
Nature of Business		
Building Construction	120	74.5
Road Projects	41	25.5
Total	161	100.0

Solid Waste Materials Typically Found in Recycled Concrete Aggregate

Table 2 sheds light on the viewpoints of experts in the Lagos metropolis on the solid waste materials that are found in recycled concrete aggregate. The experts were asked to rate their familiarity with solid waste materials that are found in RCA in construction projects. For easy assessment, a decision rule was calibrated to interpret the results. The decision rule for interpreting the mean scores (MS) was adopted and modified from Oladiran and Simeon (2023) using the scale: $1.00 \leq$ MS < 1.49 connotes 'not familiar (NF)', $1.50 \leq$ MS < 2.49 connotes 'slightly familiar (SF)', $2.50 \leq$ MS < 3.49 connotes 'moderately familiar (MF)', $3.50 \leq$ MS < 4.49 connotes 'familiar (F)' and $4.50 \leq$ MS ≤ 5.00 represents 'very familiar (VF)'.

Results from Table 2 reveal 16 solid waste materials that are found in RCA derived from C& D wastes. The construction practitioners are familiar with 15 out of the 16 investigated solid waste materials. The 15 solid waste materials present in RCA that the professionals are aware of include crushed concrete (MS = 4.08), crushed brick/block (M.S = 3.99), mortar (plaster/rendering) (M.S = 3.96), fine aggregate (M.S = 3.93), crushed granite/gravel (M.S = 3.92), wall/floor tiles (M.S = 3.78), paint and coatings (M.S = 3.75), gypsum (P.O.P) (M.S = 3.65), rebar and metal pieces (M.S = 3.64), ceramic waste (M.S = 3.61), glass (M.S = 3.59), wood particles (M.S = 3.57), aluminum sheets (M.S = 3.55), plastics (M.S = 3.52), and roof shingles (M.S = 3.51). The professionals are, however, moderately aware of Asphalt (M.S = 3.43) as a solid waste material typically found in RCA. The moderate disposition of the professionals could be attributed to asphalt's uncommon use in building projects, except when it is being used for paving roads within an Estate and a few other applications. Moreover, the findings of this study revealed that about 74.5% of the respondents' organizations investigated render building construction services, and 25.5% work on road projects. This could be the reason for the low disposition of most practitioners towards Asphalt being a solid waste material in RCA.

Table 2. Solid Waste Materials that are Found in Recycled Concrete Aggregate

Solid wastes	1	2	3	4	5	N	SD	MS	R
Crushed concrete	6	20	6	52	77	161	1.162	4.08	1
Crushed brick/block	2	17	27	49	66	161	1.058	3.99	2
Mortar (plaster/rendering)	7	16	19	54	65	161	1.148	3.96	3
Fine aggregate	4	21	20	53	63	161	1.124	3.93	4
Crushed granite/gravel	8	17	16	59	61	161	1.162	3.92	5
Wall/floor tiles	12	16	31	38	64	161	1.273	3.78	6
Paint and coatings	14	19	21	47	60	161	1.305	3.75	7

Gypsum (P.O.P)	13	20	26	54	48	161	1.252	3.65	8
Rebar and metal pieces	14	17	31	50	49	161	1.258	3.64	9
Ceramic waste	11	23	22	66	39	161	1.194	3.61	10
Glass	15	23	25	48	50	161	1.311	3.59	11
Wood particles	14	27	25	44	51	161	1.322	3.57	12
Aluminum sheets	20	20	26	42	53	161	1.383	3.55	13
Plastics	18	19	30	49	45	161	1.314	3.52	14
Roof shingles	15	28	26	44	48	161	1.328	3.51	15
Asphalt	21	27	22	44	47	161	1.400	3.43	16

Note: 1 denotes "not familiar", 2 denotes "slightly familiar", 3 denotes "moderately familiar", 4 denotes "familiar", and 5 denotes "very familiar", N denotes "Frequency", S.D denotes "Standard Deviation", M.S denotes "Mean Score", and R denotes "Ranking".

Factors Driving the Use of Recycled Concrete Aggregate for Project Delivery

Table 3 highlights respondents' views on the factors driving RAC use for construction project delivery. The respondents were asked to rate the importance of 18 factors driving the use of RCA in construction projects. For easy assessment, a decision rule was calibrated to interpret the results. The decision rule for interpreting the relative importance index (RII) of the factors was adapted and modified from Simeon et al. (2023b) using the scale where the values of RII $\geq$ 0.76 indicate most important (MI), 0.67 < RII $\leq$ 0.75 indicate important (I), 0.45 < RII $\leq$ 0.66 indicate slightly important (SI), and RII $\leq$ 0.44 indicate not important (NI). The results from Table 3 indicate that the respondents rated 10 driving factors out of the 18 investigated drivers as being the most important. These 10 drivers are those whose RII score exceeds 0.75. It includes the reduction of land converted to landfills (RSI = 0.81), local availability, and reduced cost of construction, which were jointly tied with RII= 0.80, respectively. Others, including the conservation of natural aggregate and lower carbon footprint, were jointly tied in fourth position (RII = 0.79), respectively.

In the sixth position is the promotion of a circular economy, less dependence on natural aggregate, and a reduction in mining impact, which are jointly tied with (RII = 0.78), respectively. This is closely followed by the driver that the use of RCA is suitable for a wide range of construction applications (RII = 0.77). Lastly, the driver that RCA production requires less energy compared to natural aggregate is ranked tenth with (RII = 0.76). Meanwhile, the participants rate the remaining eight driving factors as being important. This includes a reduction in the cost of transportation, reduced resource consumption, job creation/contribution to GDP, and promoting innovation, which was jointly tied with (RII = 0.75). This is followed by the lightweight characteristics of RCA in comparison with a unit weight of natural aggregate (RII = 0.72), which was ranked in 15th position. Besides, the attribute of RCA having an enhanced water absorption property (RII = 0.70) is ranked sixteenth. Meanwhile, the high thermal conductivity of RCA and its aesthetic characteristics were the least among the 18 investigated driving factors, with RII = 0.69, respectively.

Table 3. Factors Driving the Use of Recycled Concrete Aggregate

Drivers	1	2	3	4	5	N	SD	RII	R
Reduction of land converted to landfills	5	8	23	62	63	161	1.008	0.81	1
Locally available	5	8	31	52	65	161	1.040	0.80	2
Reduced construction costs	7	12	24	52	66	161	1.121	0.80	2
Conservation of natural aggregate (NA)	7	12	25	56	61	161	1.108	0.79	4
Lower carbon footprint	5	12	30	57	57	161	1.058	0.79	4
Promotes circular economy	6	9	36	52	58	161	1.069	0.78	6
Reduced dependence on natural aggregate	5	13	29	62	52	161	1.049	0.78	6
Reduced mining impact	8	13	26	57	57	161	1.131	0.78	6

Suitable for a wide range of construction applications	9	16	22	60	54	161	1.163	0.77	9
Requires less energy to produce compared to virgin aggregates	6	17	30	58	50	161	1.106	0.76	10
Reduced transportation costs	8	15	32	58	48	161	1.126	0.75	11
Reduced resource consumption	7	14	34	61	45	161	1.087	0.75	11
Job creation and contribution to GDP	9	14	38	46	54	161	1.171	0.75	11
Promotes innovation	11	18	32	43	57	161	1.245	0.75	11
Lightweight (Unit weight of RCA is less than NA)	7	23	37	57	37	161	1.121	0.72	15
Enhanced water absorption properties	9	26	36	54	36	161	1.168	0.70	16
High thermal conductivity	10	24	41	54	32	161	1.151	0.69	17
Aesthetics	10	29	32	61	29	161	1.161	0.69	17

Note: 1 denotes “not important”, 2 denotes “slightly important”, 3 denotes “moderately important”, 4 denotes “more important”, and 5 denotes “most important”, N denotes “Frequency”, S.D denotes “Standard Deviation”, M.S denotes “Mean Score”, and R denotes “Ranking”.

Extent of Recycled Concrete Aggregate Usage for Construction Works

Table 4 reveals the extent of RCA usage in potential areas of application in construction. Twenty-four areas of possible application of RCA products were presented to the built environment professionals. Participants rated each potential area of RCA application in a project on a scale of 1-10 by identifying areas where RCA was applied in the past five years. The results from Table 4 indicate that RCA was applied in varying degrees in 10 out of the possible 24 areas of application. The Ten (10) areas where RCA has been applied include hardcore filling (20.61%), backfilling utility trenches (14.01%), driveways (10.25%), parking lots (9.6%), footpaths (9.1%), road base and subbase (8.83%), concrete blocks and bricks (8.6%), concrete pavements (8.51%), decorative concrete (5.62%), and asphalt (4.91%). RCA is being applied at varying degrees among the 10 areas of construction projects that it is being applied. The result further indicates that RCA is mainly utilized as hardcore filling to make up levels during foundation construction in the Metropolis.

Meanwhile, the 14 areas that were also investigated but with zero applications include reinforced concrete works, bridge abutments, railway ballast, concrete pipes, airport runways, marine structures, industrial slabs, precast concrete, noise barriers, low-cost housing schemes, agricultural infrastructure, warehouse construction, and drainage systems. As revealed by the results of the 14 areas where RCA is not applied, the finding indicates that construction practitioners have not yet fully integrated RCA into a variety of construction works. This is primarily because of a lack of knowledge regarding the material's suitability for other areas of usage in construction projects. Table 4 reveals the extent of RCA utilization in potential areas of application in construction. Twenty-four areas of possible application of RCA products were presented to the built environment professionals. Participants rated each potential area of RCA application in a project on a scale of 1-10 by identifying areas where RCA was applied in the past five years.

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Table 4. Extent of Recycled Concrete Aggregate Usage in Construction Projects

RCA APPLICATION	F	PMU	RANK
Hardcore filling	378	20.62	1
Backfilling utility trenches	257	14.01	2
Driveways	188	10.25	3
Parking lots	176	9.61	4
Footpaths	167	9.11	5
Road Base and Subbase	162	8.84	6
Concrete blocks and bricks	157	8.57	7
Concrete pavements	156	8.52	8
Decorative concrete	103	5.63	9
Asphalt	90	4.92	10
Reinforced concrete	0	0	11
Retaining walls	0	0	11
Bridge abutments	0	0	11
Railway Ballast	0	0	11
Concrete pipes	0	0	11
Airport runways	0	0	11
Marine structures	0	0	11
Industrial slabs	0	0	11
Precast concrete	0	0	11
Noise barriers	0	0	11
Low-cost housing schemes	0	0	11
Agricultural infrastructure	0	0	11
Warehouse construction	0	0	11
Drainage systems	0	0	11
Total Usage of RCA	1834	100	

Note: F denotes "Frequency of application on the project", PMU denotes "Percentage Mean of Usage"."

Additionally, Table 5 indicates the average percentage mean utilization of RCA on construction projects. Twenty-four (24) potential areas of application of RCA on projects were presented to each respondent. For each potential area of application, each respondent was requested to indicate the number of times they applied RCA on the 24 itemized areas in their last 10 recent projects. The mean usage of RAC among the 161 respondents has been calculated and shown in Table 5. It can be seen from Table 5 that the percentage mean utilization of RCA on construction projects is 4.8%. This result indicates a low level of utilization of sustainable materials and inadequate efforts to reduce environmental effects and conserve resources. The result also suggests that RCA is not being fully incorporated into construction by practitioners in Nigeria.

Table 5. Average Percentage Mean Utilization of RCA for Construction Project Delivery

Total Respondents (A)	Total possible areas of use per person (B)	Total possible RCA use on all projects (C = A x B)	Total Usage of RCA ($D=\Sigma F$)	Total Projects where RCA was not used (E = C-D)	Mean Usage ($G=\frac{D}{C}$)	Percent Mean Usage (H = G x 100%)
161	240	38640	1834	36806	0.0475	4.75

The results of this study are discussed in this section. The solid waste materials that are commonly found in RCA that most construction professionals are familiar with comprise crushed concrete, crushed brick/block, mortar, fine aggregates, crushed granite/gravel, and wall/floor tiles. These materials' existence in RCA supports Zaharieva and Dimitrov's (2023) claim that the

C&D waste is composed of a variety of materials, including bitumen, brick, concrete, and wood. Domone and Illston (2018) add that they are typically found in RCA as impurities that reduce the mechanical qualities of concrete produced (RAC). Crushed concrete and brick were the topmost C&D waste materials found in RCA. This aligns with the findings of Kabir et al. (2012) that concrete and brick are the most common RCA utilized in place of natural aggregates. RCA from the demolition of an old structure sometimes includes a variety of materials, including concrete, glass, block, wood, floor/wall tiles, steel rebar, and pieces of brickwork. These materials are usually present because they were integrated into the original building during construction, and are thus still in place. Such materials may be advantageous; glass and wood, for example, may be processed or reused for new applications, while steel rebar can be recycled for use in new building projects.

The aggregates present within the C&D waste also lessen the amount of waste that ends up in landfills, thus preserving natural resources and lowering the carbon footprint involved in making new concrete. Besides, the circular economy is enhanced by this sustainable technique, which repurposes items that might have been disposed of. It was also discovered that there are 18 factors driving the usage of RCA in construction projects. The most important driving factors are the reduction of land converted to landfills, locally available, reduction in the cost of construction, conservation of natural aggregates, lower carbon footprint, promotion of circular economy, reduction in the dependence on natural aggregate, reduction of the impact of mining, suitability for diverse construction applications, and production process consumes less energy are the most important factors driving RCA application. The construction sector may reap several benefits from utilizing RCA, chief among them being the reduction of land converted to landfills, availability, flexibility, reduction in construction costs, the conservation of natural aggregates, and a lower carbon footprint.

The topmost driver is the reduction of land converted to landfills. Not only does recycling concrete keep waste out of landfills, but it also lowers the need for NA, which is a limited resource. RCA is made by crushing and processing leftover concrete to create aggregates that may be used in place of natural aggregates while fresh concrete is being made. Because so much less concrete waste would normally need to be disposed of in landfills, this replacement protects the environment and eases the burden on existing landfills. For example, the driver on the use of RCA, which leads to the reduction of land converted to landfills, accentuates the discoveries of Haider et al. (2014) and Junga et al. (2021) that concrete waste is one of the most common waste products generated; recycling concrete has the potential to save a significant amount of landfill space. Moreover, recycling C&D waste is a step towards circularity and provides a sustainable replacement, minimizing the strain on landfills and the need for natural resources.

Besides, the finding on lowering carbon impact corroborates the position of Tang et al. (2023) and Amir (2023) that the construction sector may effectively minimize landfill trash and lower the carbon footprint associated with the extraction and processing of natural aggregates by recycling construction and demolition (C&D) waste. Hani et al. (2015) and Pepe et al. (2016) opine that RCA is produced by processing leftover concrete, which can lessen the need for natural aggregates and lessen the environmental effect of producing concrete the conventional way. The result on savings in construction cost corroborates the result of Yao (2014) and Ali et al. (2019) that adopting recycled concrete can result in considerable financial savings. The findings from the study on natural aggregate conservation are consistent with Wijayasundara et al. (2017), who state that natural aggregate conservation is a method of closing the loop for closed-loop concrete reduction to occur.

Furthermore, the effort has a dual advantage since it not only eliminates construction waste that ends up in landfills, but it also conserves natural aggregate by eliminating quarrying. Particularly in areas where natural resources are becoming more expensive or limited, processing C&D waste into RCA may be less expensive than obtaining natural aggregates. Besides, the findings on RCA being locally available buttressed the position of Amir (2023) that, because of the availability of the material, transportation cost is reduced in relation to the purchase of the material. In addition to lowering prices, this local sourcing boosts regional economies and lessens the negative effects of transportation on the environment. Moreover, the findings also revealed 10 areas of application of RCA in construction projects.

This includes hardcore filling, backfilling utility trenches, driveways, parking lots, footpaths, road base and subbase, concrete blocks/bricks, concrete pavements, decorative concrete, and asphalt. The topmost utilization of RCA as hardcore filling material is no surprise and expected because it is the major material used for making up levels before oversite concreting is placed in foundation works. The results of the fourteen areas where RCA is not utilized suggest that, in the Nigerian construction industry, construction practitioners have not yet completely incorporated RCA into the manufacture of RAC for a variety of construction applications on a commercial scale. This is primarily because of a lack of knowledge regarding the material's suitability for other areas of usage in construction projects. The low adoption rate of RCA corroborates the positions of Simeon et al. (2024) that although the Nigerian construction sector heavily relies on concrete as a construction materials, yet, there is minimal focus on sustainable materials.

Conclusion

The study draws the following conclusions based on its findings of the study. Construction practitioners acknowledge the heterogeneity of materials present in RCA. They are familiar with the presence of materials such as crushed concrete, crushed brick/block, mortar, fine aggregates, crushed granite/gravel, and wall/floor tiles, among other materials. Meanwhile, the professionals are moderately familiar with the presence of asphalt among RCA materials. Construction practitioners' familiarity with the presence of different forms of C&D waste translates into enhanced management of waste, recycling, environmental sustainability, and cost-effectiveness in projects. There are as many as 18 important factors driving the usage of RCA in construction projects. The most important driving factor is the reduction of land converted to landfills. This translates to less demand on landfill space, more reuse of demolition debris, sustainability, and less environmental damage by recycling concrete rather than throwing it away. The present level of RCA adoption on construction projects falls short of its potential. Given the present market conditions in the Nigerian construction industry, the business of producing RAC through the usage of RCA will not thrive. Moreover, RCA is mainly applied in 10 out of 24 investigated areas of construction projects. This indicates that RCA has not been adopted fully by all stakeholders in the construction projects.

Besides, out of the 10 areas of application, RCA is mainly utilized as hardcore filling for foundation works. This indicates that attention has not been fully paid to other eco-friendly applications of RCA. The study, therefore, recommends that construction professionals should employ RCA in the 14 areas of non-application which include; reinforced concrete works, bridge abutments, railway ballast, concrete pipes, airport runways, marine structures, industrial slabs, precast concrete, noise barriers, low-cost housing schemes, agricultural infrastructure, warehouse construction, and drainage systems where they are not employed to optimize RCA sustainability attributes through circular economy strategies. This may be achieved by amplifying awareness of RCA non-deployment among built industry stakeholders in the 14 construction areas where they are not engaged. Besides, construction practitioners employ RCA in areas where they are not engaged to optimize RCA eco-friendliness through circular economy strategies. This may be accomplished by specifying the material for construction works and developing the requisite technology to fully unlock its potential.

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