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Comparative Analyses of Circularity Practices in Civil and Construction Engineering Between UK and Nigeria

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Abstract

The circular economy in the civil and construction engineering sectors is gaining momentum globally. The inadequate waste management system, especially in emerging nations, is quite concerning. Various waste sources such as construction and demolition (C&D), industrial wastes as well as agricultural wastes such as cassava peel, rice husk, and coconut fibre have been utilized in developing construction products. This study adopts the UK (United Kingdom) and Nigeria as two cases with critical analyses of the status quo and recommendations for promoting circularity. The existing studies on the circular use of waste construction products were comprehensively reviewed by mapping them against the Technology Readiness Level (TRL). The study addressed three research questions: (1) the existing locally available wastes used in civil and construction industries in the two studied countries, (2) the effects of these wastes on the properties of new construction products, and (3) visions to enhance circular use of wastes on civil and construction engineering practices. It is found that both countries have abundant industrial, agricultural, and demolition wastes that are potential materials for circularity in construction. While the TRL of utilizing these wastes is at an advanced stage in the UK, there is still a need for more concerted efforts to bring those wastes in Nigeria to a higher TRL. This study contributes to the existing body of knowledge by mapping the three aforementioned questions between the two studied countries, shedding light on continuous work in enhancing circular practices across the global civil and construction sectors.

Keywords

Construction and demolition wastes, Circular economy, Civil engineering, Technology readiness level, Waste management

Introduction

The construction industry accounts for almost 50% of waste generation and annual resource consumption worldwide [1]. Wastes from C&D and other industrial sectors as well as agricultural by-products have been studied for their feasibility of circular use, including both developing and developed markets. Circularity, or circular economy for C&D and other industrial/agricultural wastes, provides the alternative to conventional disposal of wastes [2, 3] by addressing the reduce-reuse-recycle principles to turn wastes into resources [4]. In mixing the bespoke sustainable products, various waste sources have been studied at different TRLs as defined by NASA (National Aeronautics and Space Administration) [5] and widely used to define the development of technological innovation from initial concept (TRL1) to market readiness (TRL9). It is inferred that the hierarchy of TRL could be applied in different technological contexts, such as the circularity of industrial wastes in the civil and construction sectors in this study. On the other hand, for the same technology, i.e., circularity, geographical or cultural differences could cause the TRL at different stages. As indicated in [6], regional differences could cause the status quo of C&D waste management, e.g., developing economies may rely more on governmental support, whilst developed markets could have established the supply chain in the recycling market. Currently, there is a lack of mapping between case study countries at different development stages, in order to address the issue of circular economy in different geographic or cultural contexts. Studying this issue is important based on the facts that: (1) waste generation, resource consumption, and greenhouse gas emission are the main concerns worldwide during the rapid urbanization process [7], and (2) implementation of circularity could still highly rely on local factors, and it is critical to understand the regional context and aspects [1]. Adopting UK and Nigeria as cases from two different regions addresses three research questions, namely: (1) what are the existing and potential local wastes being circularly used in the civil and construction industries in UK and Nigeria?, (2) how would waste sources affect the engineering properties of new products?, and (3) how to promote the circularity use of wastes in civil and construction engineering according to TRL. Through mapping the two countries' research and practices in the circular use of industrial wastes for construction and civil engineering, this study provides insights into the ongoing and continuing work on Circular Economy for the construction industry across the globe.

Worldwide, there have been numerous studies or practices of circularly using C&D or other industrial and agricultural wastes in civil and construction engineering at different TRLs. For example, recycled coarse and fine aggregates can be reused as raw materials in cementitious products (e.g., concrete or mortar). These reformed raw materials could be adopted to replace either natural aggregates or cementitious binders. Multiple studies can be found in exploring these different waste streams in producing potential building or civil engineering products.

A global overview of research using local waste sources in civil and construction fields

Ceramic and fired bricks, due to their wide application, can often be identified as recyclable waste sources. For example, Zawrah et al. [8] mixed waste-fired clay bricks with granulated blast-furnace slag (GGBFS), another industrial by-product, at different mixture percentages to produce geopolymers. Similarly, by utilizing wastes bricks, sand, and GGBFS, Youssef et al. [9] investigated the production of geopolymer-based building materials (i.e., bricks). Both studies demonstrated positive outcomes by integrating GGBFS and waste bricks to manufacture new building products with promising physical and mechanical properties whilst also achieving economic and environmental benefits. Robayo et al. [10] demonstrated the alkaline activation technique using locally available ceramic and brick wastes as a precursor for the production of cement. The optimal combination between the cement made from the brick wastes and the traditional Portland cement was identified in terms of compressive strength and microstructural condition. Yıldırım et al. [11] also explored the alkali-activated binders produced from C&D wastes made of masonry units and found that C&D wastes from red clay bricks, hollow bricks, and roof tiles could be optimized to produce binders with satisfactory compressive strengths. Gorospe et al. [12] studied cement mortar mixed with crushed glass, glass beads, and expanded glass. It was found that cement mortar with glass aggregates could be beneficial with proper aggregate type and amount.

Agricultural wastes are recently being processed for use as SCM (Supplementary Cementitious Material) and as aggregates in concrete. This practice is very common in most countries in Sub-Saharan Africa, where agriculture is a main business. In the course of processing agricultural products either for food or industrial use, large quantities of agro-waste are generated, whose disposal becomes a major issue. Most often than not, these wastes are piled in landfill and burnt for no benefit in return to give room for subsequent wastes generated. Where they are not burnt, they are allowed to rot, oozing an obnoxious odor to the environment. Processing these wastes for use in producing SCMs or aggregates will not only manage the wastes but also ensure circularity.

The use of rice husk ash (RHA) as SCM was first patented in 1924 [13]. Since then, it has been used in several projects. The Michigan Team has used RHA to build a concrete ship [14]. Filho et al. [15] and Tashima et al. [16], are among other authors who have reported that when rice husks are burnt up to 700 °C, the resulting ash has high silica content for pozzolanic reaction making it a potential material for replacement of cement in concrete. Salau and Olonade [17] also established cassava peel ash as a potential pozzolanic material. Cassava peels are obtained from cassava tubers when peeled for industrial or domestic uses. About two million tons of cassava peel are generated annually. When burnt up to 700 °C for 90 min, the ash obtained contained a combined silica, alumina, and ferric content far above 70% [17]. It was also reported that the strength activity index of concrete containing up to 20% cassava peel ash (CPA) as a replacement for cement ranged between 75 and 86% [18]. Other bio-wastes that have been reported to possess pozzolanic materials for use as SCM includes coconut shell ash [19], corn cob ash (CCA) [20], palm kernel shell ash [21], sugarcane bagasse ash [22] among others. Nevertheless, many of these materials are still at very low TRL as compared to fly ash and silica fume are well established and integrated in standards in most countries in Europe and America.

Existing wastes in UK and Africa

Aygün and McCann [23] utilized recycled glass in producing bead panels. The recycled glass is being used as fine and coarse aggregates, cement replacement, or for preparation of activation solution used for geopolymer concrete. In Africa including Nigeria, finding an alternative binder to the traditional Portland cement is of growing urgency [24]. Olonade and Mohammed [24] reviewed bio-wastes as potential raw materials for alkali-activation in cementitious products. These waste sources included ashes from rice husk, cassava peel, sugarcane straw, corn cob, and coconut shells, which could be feasible for alkali activation but had not been fully explored.

Among them, cassava is a source of food for 80% of people in Sub-Saharan Africa [25]. Nigeria is the largest producer of cassava which has thick peels creating large challenges for effective disposal. According to Schmidt et al. [25], reusing cassava wastes potentially for construction materials could not only save landfill spaces, and prevent environmental pollution from burning, but also accelerate rural development. In the follow-up study by Schmidt et al. [26], it was further described the potentials and shortcomings of the circular use of these agricultural wastes in sustainable concrete production. Specifically, a three-step process and two possible ways of reusing agricultural by-products for sustainable concrete technology were described by Schmidt et al. [26], inclusive of usages in organic admixtures and inorganic cement replacement.

Nigeria equally has a substantial share of global production of corn with an estimated annual production of 11 million metric tons in 2020. With this figure, Nigeria is the second largest producer of corn in the continent after South Africa, while 25% of the weight of corn stalks is corn cob [27]. Apart from the traditional use of corn cobs as a fuel, feed filler and bio-abrasive [28], when corn cob is incinerated into ash at a temperature of 650 ˚C, it is found to possess pozzolanic properties making it a suitable material for use as cement replacement [29]. This has been demonstrated by Adesanya and Raheem [30], who reported that the strength activity index of concrete containing CCA is more than 75%. Palm kernel shell is another potential bio-waste available in Nigeria for use in concrete production. Apart from being used as SCM, it is also a potential aggregate in concrete [30].

Methodology

This study selected UK and Nigeria as two case studies of the circular use of industrial/agriculutral wastes in the civil and construction industry. A case study focuses on a special unit [31], such as the regional context of circularity in the civil and construction sectors in this study. The case study method explores a real-life and contemporary system through detailed and in-depth data collection involving various sources of information, leading to case descriptions and case themes [32]. In this study, UK and Nigeria were the two units, and the sources of information were secondary literature from published research outputs or practices. Gustafsson [33] advised adopting a single case study or multiple cases. This study includes more than one single case in order to understand the differences and similarities between the cases [34]. Researchers are able to analyse the information both within each context and between contexts [35]. Further, when the case studies are compared to each other, researchers are enabled to update the literature with significant influences based on both contrasts and similarities [36]. Therefore, selected references were reviewed through parallel comparative analyses of circularity research and practices between the two countries. Each selected reference from the studied country or context was coded with keywords inclusive of waste sources, products studied, findings or summary, and readiness of technologies, as demonstrated in table 1 and table 2. All used materials are nanoscale materials.

Results and Discussion

Table 1 and table 2 summarized the selected references in UK and Nigeria, respectively. Selected references in the UK (i.e., table 1) are from various sources corresponding to different TRLs. For example, laboratory tests corresponding to TRLs 3 and 4 [5] for feasibility studies can be found in numerous published studies. Similarly, these tests can be found also in Nigeria as seen in table 2.

It can also be found in table 1 that the UK's existing research and development on circular use of various wastes have crossed TRLs, from laboratory tests, demonstration of real-life projects, and the highest level of technological readiness as evidenced in practitioners with established business models [41]. Various industrial wastes including but not limited to C&D wastes are being studied and practiced in the UK. C&D wastes are the most commonly generated solid wastes worldwide and contribute to a significant proportion of global urban wastes. It is also based on the fact that C&D wastes have been widely studied, and their application and mass production of recycled products have reached the highest TRL. Besides C&D wastes, various other solid wastes are being studied in both countries. Local availability and regional contexts would be considered for adopting recycled sources [42]. These local and regional factors also determine the different sources of waste being applied as seen in table 1 and table 2. In the UK, plastics, metals, glass, and seafood wastes have been utilized for building components. It could be implied that TRLs of products or processes are related to the types or sources of waste. For instance, the widely adopted C&D wastes have reached higher technology readiness. In comparison, other locally available wastes such as seafood shells are more at prototyping or qualifying stages corresponding to TRL 7 or 8 according to NASA [5].

According to the studies conducted in Nigeria, large amounts of agricultural byproducts have been utilized as cementitious binders or replacements for conventional aggregates. All these studies have stayed at the laboratory tests stage except for the use of CPA, which is already used to build a concrete structure consisting of various structural elements such as beams, walls, columns, and footings. Generally, through proper mix design of replacing cement or natural raw materials, the comparable or acceptable properties of cementitious products can be achieved. Similarly, effective design can be achieved with recycled glass or other waste sources as seen in table 1. These end products may not be limited to cementitious products such as concrete or mortar, but various building components, e.g., wall cladding, insulation materials, or even off-site manufactured building units. For these waste sources and products to achieve higher TRLs, various factors are worth investigating, including (1) end applications of products (e.g., Lego-style or interlocking blocks) for local infrastructure projects. Therefore, the key engineering properties can be targeted accordingly by conforming to existing standards; and (2) a wider application or higher TRL does not solely depend on the engineering properties of end products, but a wider picture by also considering environmental, economic,

Table 1: Summary of selected studies in the UK.

Waste source(s)	Products studied	Findings or summary	Readiness of technologies	Ref.
Crushed recycled glass	Recycled glass bead panels comprising two fiberglass facing sheets surrounding an inner core of recycled glass beads bonded in a matrix of polyurethane resin potentially used for off-site construction	The acoustic test demonstrated the efficacy of the panels in providing acoustical insulation both as highway noise barriers and in a building structure. Mechanical strength tests indicated an additional reserve of strength within recycled glass bead cores.	Laboratory tests	[23]
Crushed recycled glass	Recycled glass bead sandwich panel	Through flexural bending tests in comparison to the design ultimate moments incorporating the recommended partial factors, it showed that the design moment resistances are conclusively safe sided across a range of glass bead diameters, panel depths and bead core contents.	Laboratory tests	[37]
Various C&D wastes including concrete, bricks, plastic, metals	Individual panels of the building block and the structural frame for new construction and retrofitting	The project demonstrated the feasibility of manufacturing modular panel that was (1) sustainable and cost-effective -using more than 70% by weight of C&D wastes, (2) safety and energy efficient-meeting Eurocode standards for fire safety, thermal insulation, and acoustic insulation, and (3) Customization potential -multi-layered, modular, and prefabricated building block	Project demonstration	[38]
Various solid wastes including polyester duvets, waste oyster shell, etc.	Whole house built by reusing locally recycled wastes to construct building insulations and wall cladding	Local wastes including duvet, toothbrush was reused as building insulation, oyster shells were reused as wall cladding. This was the first permanent building constructed from waste in the UK.	Prototyping through practices and demonstration	[39]
Discarded champagne corks and seafood shells	Garden pavilion was designed and to be built by reusing various sources (e.g., oyster and lobster shells) that following the principles of Circular Economy	There was a promising potential to integrate design for deconstruction and dissemble for the single-story pavilion, whilst achieving minimum carbon footprint. The project was also driven by client who required the optimum sustainability (e.g., renewable energy and reusing locally available wastes)	Beyond the prototyping stage and becoming ready for implementation into existing practices of circularity in building components	[40]
Recycled aggregates from local C&D wastes	Recycled aggregates categorized in different sizes after washing crushed C&D wastes locally available, and cementitious products such as Lego-style blocks	A well-established processing system owned by the local business has supplied both processed aggregates from C&D wastes and relevant trademarked products that have been applied in various civil and infrastructure projects. These products include interlocked blocks for civil and infrastructure engineering. The first five years of business operation have been claimed to save half a million tons of waste ending up in UK landfills.	Successful mission to the highest level of readiness	[41]

and even cultural perspectives. For example, the support from governmental authorities [6], the market for the circular use of reclaimed materials, and client requirements can play significant roles in driving the circularity of materials in civil and building projects. Finally, circular economy for civil and construction engineering is a global momentum. More cross-country comparisons could be conducted to extend this study in incorporating regional factors for driving circularity to higher TRLs.

Conclusion

This study adopted UK and Nigeria as two comparative cases for analyzing the circular use of reclaimed materials in civil and construction sectors. It addressed three main research questions related to (1) the sources of waste materials for circular use in construction and civil engineering sectors, (2) the effects of these wastes on the properties of end products, and (3) visions of promoting circularity in the different regions. Agricultural wastes were identified as sources for circular practices in the Nigerian context, whilst multiple industrial wastes were found in UK with different levels of applications. Adding these wastes to partially or fully replace traditional sources were found with certain promising outcomes. For example, recycled glass contained in structural panels did not sacrifice the mechanical strength. These waste sources were correlated to TRL or technological readiness. For example, demolition wastes from construction projects had been relatively well established in the UK with existing business implementation. Other wastes, e.g., seafood shells for wall cladding had been undergoing prototyping and demonstration. In Nigeria, locally available agricultural wastes (e.g., CPA) had been studied in laboratories as replacements to cement or other natural aggregates. Through proper mix design with identified optimum replacement ratios of these waste streams to meet the required engineering properties of end products, e.g., concrete compressive strength. In order to move this laboratory research into the next stages of TRL, a

Table 2: Summary of selected studies in Nigeria.

Waste source(s)	Products studied	Findings	Readiness of technologies	Ref.
Bone ash produced from cattle bones	Lateritic soil from bone ash as the topmost local building material in Nigeria	The optimum compressive strength obtained met the specifications for laterite bricks of compressive strength of 1.65 MPa by the Nigerian standard	Laboratory tests	[43]
CPA	CPA: an emerging pozzolanic material	Cassava peels are available in large quantities in Nigeria and disposed of for no benefit in return. Cassava peel ash burnt at a temperature of 700 °C for 90 min contained amorphous silica in adequate quantity and state for pozzolanic reactivity. Blended cement-CPA mortar containing 15% proportion of CPA has strength comparable with that of normal mortar. CPA replacement up to 15% of cement was found to have strength activity index above 70% and has the potential to resist elevated temperatures up to 600 °C for about 90 min.	Laboratory tests/ Concrete structure prototype already built	[17, 18, 44]
RHA	Exploiting the potential of RHA as a supplement in cement for construction in Nigeria	5% partial replacement cement with RHA at day 28 average compressive strength value of 25.4 N/mm^2 compared well with 0% partial replacement of cement with RHA of 26.28 N/mm^2. This shows that at 5% partial replacement of cement with RHA can be used for structural concrete and at 15% replacement or more it can be used for non-structural construction works or lightweight concrete construction.	Laboratory test	[45]
RHA	Microstructural characterisation, physical and chemical properties of RHA as viable pozzolan in building material: a case study of some Nigerian grown rice varieties	RHA is an effective pozzolan that can contribute to the mechanical properties of concrete. The relatively high content of silica shows that RHA which is an agricultural waste can be converted into a valuable product that has so many industrial and domestic applications thereby taking care of the disposal problem associated with the husk	Laboratory test	[46]
Palm kernel shell ash/Palm Kernel shell	The use of palm kernel shell and ash for concrete production	The compressive strength of the concrete and mortar produced using palm kernel shell to replace coarse aggregate and palm kernel ashes to replace cement were lower relative to those made with limestone aggregate and Portland cement.	Laboratory test	[47]
CCA	Partial replacement of cement with CCA	The results showed that the concrete strength decreased with increasing replacement with the CCA. The 28 days compressive strength for 5%, 10%, 15%, 20%, and 25% replacement was 28.78 N/mm^2, 26.22 N/ mm^2, 22.33 N/ mm^2, 20.27 N/ mm^2, and 17.33 N/ mm^2, respectively while its flexural strength for same age for 5%, 10%, 15%, 20%, and 2% replacement was 9.98 N/ mm^2, 8.58 N/ mm^2, 7.82 N/ mm^2, 6.56 N/ mm^2, and 5.72 N/mm^2, respectively.	Laboratory test	[48]

more comprehensive evaluation of influence factors beyond engineering properties should be considered. These factors include but are not limited to environmental, market, and client requirements. The biowastes identified in Nigeria were only discussed for circular research or practices in civil and construction industry in this study, it should be aware that biowastes could have other circularity values beyond being used in civil and construction engineering. For example, bio wastes could be back to their natural cycles and be reused to fertilize soils for agricultural purposes. The current study was limited to two countries' contexts to address the regional factors of promoting the circularity of construction and civil engineering sectors. More future work could extend this study by including both primary and secondary data sources to address the similarities and discrepancies of implementing the circular economy of applying reclaimed wastes.

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None.

Conflict of Interest

The authors declare that there is no conflict of interest associated with this study.

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