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Barriers impeding circular economy (CE) uptake in the construction industry

Safowaa Osei-Tutu
Built Environment Division, Building and Road Research Institute, Kumasi, Ghana
Joshua Ayarkwa
Department of Building Technology,
Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, and
Dickson Osei-Asibey, Gabriel Nani and Aba Essanowa Afful
Department of Construction Technology and Management,
Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

Abstract

Purpose – This study aimed to identify barriers impeding circular economy (CE) uptake in the construction industry in literature, categorize them for the development of a framework and to seek the interrelationships among the categorized barriers. This allowed for identifying integrated solutions to holistically address the barriers. The study also sought to identify the "hot" themes, the knowledge gaps and future research directions on barriers impeding CE.

Design/methodology/approach – Forty-eight relevant articles were desk reviewed from different construction peer-reviewed journals and published conference papers. A scientometric analysis allowed for co-occurrence of keywords relating to CE. A content analysis enabled the identification of 79 barriers impeding the uptake of CE in the construction industry which were further categorized into six distinct categories for the development of a framework showing the interrelationships among the categorized barriers.

Findings – The identified barriers include construction sector inertia, lack of design standards, lack of knowledge, awareness and understanding, design cost, and perception of second-hand materials as substandard among others. The study categorized the identified barriers for better understanding into six different groups: cultural barriers, social barriers, environmental barriers, economic barriers, technical barriers and technological barriers. Strategies to address the barriers were also proposed. The interrelationships among the various barriers were also shown in a proposed framework to educate professionals on the interconnectivity of the barriers.

Practical implications – Categorization of the various barriers impeding CE uptake contributes to the body of knowledge. Also, the interrelationships among the various categorized barriers in the framework will enable construction professionals make informed decisions regarding the successful integration of CE in the industry, better appreciate the barriers that impede CE uptake and apply strategies to holistically address the barriers. This will expand current knowledge outside the narrow scope of isolated barriers.

Social implications – To the global construction industry, the review presents a list of barriers and their interrelationships that could provide implementation strategies for the uptake of CE in the industry.

Originality/value – The geographical scope of this study is not limited, and therefore encourages wide applicability of the findings to the global construction industry.

Keywords Barriers, Circular economy (CE), Construction industry, Built environment

Paper type Literature review

Introduction

Construction-related activities have always been documented to negatively impact the environment and its ability to sustain future generations. A phenomenon closely tied to construction-related activities is the production of Construction Demolition Waste (CDW), a result of rebuilding, remodeling and demolition activities within the building industry (Wu *et al.*, 2017).

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Due to the amount of waste generated annually from construction-related activities, CDW is presented as a challenge in the global construction industry. A report from Eurostat (2020) highlighted that CDW is in essence the largest waste stream, accounting for about 30–40% of all total solid waste generated in the construction industry, amounting to about 924 million tones of wasted materials (Eurostat, 2020).

Over the years, there have been calls to urge policymakers and stakeholders in the construction industry to curb the CDW menace. However, all such efforts have been focused on reusing or recycling materials (Shen and Qi, 2012; Charef *et al.*, 2021b; Wijewansha *et al.*, 2021). The adoption of reuse and recycling methods has continued to result in large volumes of waste disposed of in landfills, and in some cases, illegally dumped without environmental protection measures (Esa *et al.*, 2017). This is often because the waste management processes are inefficient.

A report by the World Economic Forum (2016) revealed that a mere 20–30% of CDW is recovered globally. This recovery can be increased by the move toward a circular economy (CE). As proposed by Ellen MacArthur Foundation in 2015, CE considers a holistic approach to ensure zero waste generation. It allows for the protection of the environment from the negative impacts of construction-related activities, through the reduction and ultimate elimination of waste produced (Lieder and Rashid, 2016). According to the Ellen MacArthur Foundation (2018) and Wijewansha *et al.* (2021), CE is a concept that is influenced by many schools of thought, such as cradle-to-cradle design, performance economy, biomimicry, industrial ecology, natural capitalism and blue economy, all ultimately leading to sustainable development within the built environment (Kirchherr *et al.*, 2017). Grdic *et al.* (2020) highlighted some European countries that have successfully implemented CE strategies. These researchers outlined that CE can promote the efficient use of resources and minimize waste generation. On the economic front, the adoption of CE strategies has increased the Gross Domestic Product (GDP) of EU by almost 4% (Eurostat, 2020). Since its introduction, empirical studies by Bouzon *et al.* (2015), Bigolin *et al.* (2016), Ghisellini *et al.* (2018) and Tennakoon *et al.* (2021) have proved that CE strategies are environmentally friendly and have resulted in the reduction of waste, particularly in the manufacturing sectors, where it was first proposed. It is thus necessary to ensure that such gains are equally achieved in the construction sector in which it is being adopted (Wijewansha *et al.*, 2021). Improved productivity and addressing the ill performances from the orthodox linear construction approach are among the many benefits the construction industry can reap from adopting CE strategies (Ellen MacArthur Foundation, 2015).

Despite the well-documented benefits of CE strategies in other industries (Boon and Anuga, 2020), its adoption in the construction industry is not without challenges and barriers. What then are the global barriers impeding the uptake of CE strategies within the construction industry? How can these identified barriers be solved and what are the implications of these barriers for professionals, organizations and the state, regarding the uptake of CE in the construction industry?

Consequently, this study undertakes a scientometric review of literature to unearth what is currently known on the barriers impeding CE uptake in the construction industry and thereby identify knowledge gaps, future research directions and propose solutions to the identified barriers. The scientometric review was adopted as it has in recent studies been used to review relevant literature in the construction industry. Such recent scientometric reviews include studies by Zhong *et al.* (2019), Ghosh and Hasan (2020) and Kukah *et al.* (2022). The study further subsumes the barriers under various categories and proposes a framework revealing the interrelationship between the identified barriers. A global perspective of the barriers identified through this literature review can serve as a useful checklist for future empirical research in the area of CE as well as aid policymakers in making informed decisions regarding the successful integration of CE into the construction industry.

Overview of circular economy

The first time the term Circular Economy was used, was in the works of Pearce *et al.* (1990). These authors proposed the Sustainable Economic Development that highlighted a link between the economy and the environment. This was in contrast at the time to the conventional economic paradigm, which was based on effective cost–benefit principles. The main rationale behind CE is the development of systems that go beyond linear "take-make-dispose" economic models and focus on closing the loop of materials and energy that maintain the value of resources in the economy (Pearce *et al.*, 1990). However, the CE concept only gained prominence after 2015 when Ellen MacArthur Foundation moved for the use of the concept.

The Ellen MacArthur Foundation (2015, p. 7) defined CE as "restorative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles". This input by the Ellen MacArthur Foundation led to various definitions by several researchers. According to Geissdoerfer *et al.* (2017), CE can alternatively be defined as "a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops". Mendoza *et al.* (2019) further suggested CE as a concept that seeks to narrow resource loops by involving eco-efficient solutions that decrease resource usage and environmental impacts per unit of product or service. Slowing resource loops requires prolonging and increasing the use of products to preserve their value over time while closing resource loops enables up cycling to reinstate or create new value from used materials (Bocken *et al.*, 2016).

The principles of CE were laid by Ghisellini *et al.* (2016) who posited that the CE concept involved decreasing waste, reducing pollution, extending the useful life of products and materials, and regenerating natural systems. These principles encompassed the popularized 10 Rs in CE, i.e. R0 Refuse, R1 Rethink, R2 Reduce, R3 Reuse, R4 Repair, R5 Refurbish, R6 Remanufacture, R7 Repurpose, R8 Recover and R9 Recycle (Potting *et al.*, 2017; Vermeulen *et al.*, 2019; Peiró *et al.*, 2020). It has been proposed that the application of these Rs, tailored to the construction industry would help achieve CE (Pomponi and Moncaster, 2017).

Unlike the linear method of construction whose main focus is on the completion of a project, the CE concept goes beyond the project completion and focuses on the End of Life (EOL) phase of all construction activities as well (Guerra and Leite, 2021). As revealed by the seminal work of Geissdoerfer *et al.* (2017), CE is a "cradle to cradle" concept as compared to the "cradle to grave" concept popularized in the global construction industry. The slow uptake of CE in the construction industry may be ascribed to the complex nature of the construction industry (Charef *et al.*, 2021b).

Unlike a manufactured product, a building is vastly different in terms of its design, construction and use. Indeed, there is the added problem of each client needing to have a bespoke building characterizing the uniqueness of construction projects (Geissdoerfer *et al.*, 2017). Moreover, the management of the building from its design, construction and final demolition involves a wide range of professionals and stakeholders each with different stakes and skills (Pomponi and Moncaster, 2017).

Each of these problems compounds to present a complex view of the construction industry (CI), and thus an impediment to the uptake of CE (Pomponi and Moncaster, 2017). The adoption of CE in the CI should aim to address all potential challenges presented by the complex nature of the CI while proposing solutions that satisfy the needs of all stakeholders involved in construction projects, phases of construction and overarching sustainable development goals (Charef *et al.*, 2021b).

Definition of barriers to CE

Most often, researchers use barriers and challenges interchangeably. Different dictionaries have come up with different definitions of barriers. Collin's English Dictionary (2015), Cambridge Dictionary (2015) and Oxford English Dictionary (2015) define barriers as something such as a rule, obstacle, law or policy that makes it difficult or impossible for something to happen. A barrier can be defined as anything which prevents or discourages the implementation of a particular concept, technology or innovation (Hilson, 2000). Also, a challenge or barrier can be defined as an issue that would hinder the improvement of a particular practice (Ye *et al.*, 2020).

The operational definition for barriers in this study is:

> The specific deterrents which inhibit, dissuade, or discourage the implementation of principles of Circular Economy in the construction industry.

Research process

The review method used in this study adopted the procedure of previous researchers (Darko *et al.*, 2017; Geng *et al.*, 2019; Afful *et al.*, 2021; Ograh *et al.*, 2021; Grafström and Aasma, 2021). The study combined scientometric analysis with content analysis to screen, select and analyze articles from which relevant themes could be obtained for this review.

Drawing from previous studies, the following steps were adopted. First, there was the search for CE articles within the CI, retrieval of relevant papers and a scientometric analysis which allowed for network maps to be drawn to visualize the co-occurrence of keywords for the identification of knowledge gaps, current research trends and future research focus. A content analysis was then undertaken to allow for the identification of barriers to CE. This was validated by assessing the various contributions of authors from selected publications. This literature review relied on the Scopus database, because it is a dominant and arduous search engine that helps to retrieve appropriate construction journal articles and is used widely across the globe by many researchers (Afful *et al.*, 2022; Kukah *et al.*, 2022). In addition, a wide range of researchers has utilized the Scopus database for works of this nature (Hong and Chan, 2014; Darko *et al.*, 2017, 2018; Geng *et al.*, 2019; Afful *et al.*, 2021). Furthermore, the Scopus database is known to perform better than other web searches in the capacity of coverage and accuracy in delivery (Deng and Smyth, 2013; Geng *et al.*, 2019; Afful *et al.*, 2021). Using the following search string in the "Article title/Abstract/Keywords": "circular economy" AND "barriers" and "construction industry" OR "built environment", the Scopus search engine made available 130 papers. The search string used was gathered from similar literature review papers by Akinde *et al.* (2020), Gue *et al.* (2020) and Charef and Emmitt (2021).

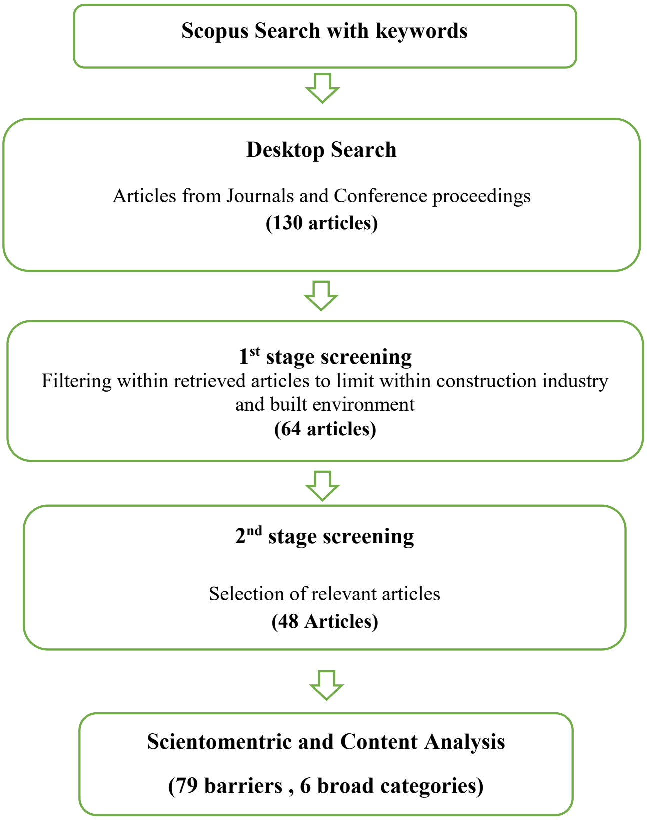
The initial 130 documents retrieved included journals, and conference proceedings (both construction and non-construction related). All articles were in English Language and thus did not require language screening criteria. A second screening was undertaken within the 130 documents obtained, to further restrict papers to the construction industry and the built environment as contextually scoped for this study. This was done with the use of keywords "circular economy, barriers" or "challenges, construction, built environment". A total of 64 articles passed this screening to the next stage.

Next, the 64 papers were filtered to eliminate any articles which did not deal with the topic area or did not play a major role in the relevance of the study. Also, some articles of sub-par quality in non-reputable journals were eliminated to improve the quality of conclusions drawn. For instance, articles with poor grammar, one week period from submission to publication as well as questionable research methods and findings were excluded. Furthermore, articles that had the topic as a significant sub-theme were included for analysis. For instance, Häkkinen and Belloni (2011) focused on barriers and drivers for sustainable buildings but identified the concept of refurbishment as a key barrier from the contractor's perspective. They further detailed the concept of refurbishment and identified some barriers although they did not specifically mention the term CE. This final screening produced 48 articles used in the review. The content analysis allowed for the identification of 79 barriers which were further classified under six broad themes, followed by the establishment of a proposed framework showing the interrelationship of the barriers identified. The research process is captured in Figure 1, showing the screening stages and articles obtained at each stage.

The selected 48 articles which were subsequently reviewed are tabulated in Table 1. These publications were ranked according to the number of times the article has been cited by other studies obtained from Google Scholar citations.

These documents primarily included journal articles and conference proceedings. The selected articles were not restricted by year to broaden the findings. In the end, the 48 selected articles spanned a period from 2006 to 2021 as seen in Figure 2. This then validates the currency of research in CE, particularly within the built environment, as seen in similar studies by Grafström and Aasma (2021), and Charef *et al.* (2021b).

The trend line within the graph shows a gentle ascent of literature on CE within the built environment. Furthermore, these selected documents were published from countries like the United Kingdom, China, the United States of America, Brazil, Chile, Spain, Turkey, Australia, Denmark and Germany as shown in Figure 3.



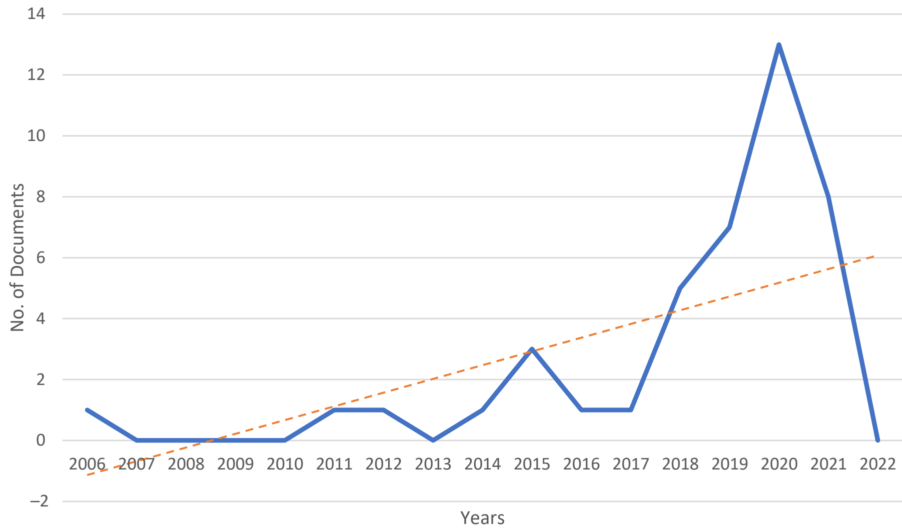
Source(s): Author(s) Construct, 2022

Figure 1.
Systematic research process

Code/ Rank	Authors	Date	Citation
R1	Häkkinen, T. and Belloni, K.	2011	646
R2	Huang, B., Wang, X., Kua, H., Geng, Y., Bleischwitz, R. and Ren, J.	2018	325
R3	Wu, Z., Yu, A.T.W. and Shen, L.	2019	192
R4	Jaillon, L. and PoonC.S.	2014	178
R5	Osmani M, Price, A. and Glass, J.	2006	156
R6	Mahpour, A.	2018	133
R7	Densley Tingley, D., Cooper, S., and Cullen, J	2017	100
R8	Ghisellini, P., Ji, X., Liu, G. and Ulgiati, S.	2018	93
R9	Hosseini, M. R., Raufdeen, R., Nicholas, C. and Steffen, L.	2015	89
R10	Bouzon, M., Govindan, K. and Rodriguez, C.M.T	2015	88
R11	Yuan, Z., Bi, J. and Moriguchi, Y.	2020	76
R12	Zaman, K., bin Abdullah, A., Khan, A., bin Mohd Nasir, M.R., Hamzah, T.A.A.T. and Hussain, S.	2016	67
R13	Sanchez, B. and Haas, C.	2018	64
R14	Chileshe, N., Rameezdeen, R., Hosseini, M. R., Martek, I., Li, H. X, and Panjehbashi-Aghdam, P.	2018	58
R15	Grafstrom, J. and Aasma, S.	2021	49
R16	Kifokeris, D, and Xenidis, Y.	2017	45
R17	Campbell–Johnston, K., Cate, J. T., Elfering-Petrovic, M., and Gupta, J.	2019	39
R18	Akinade, O., Oyedele, L., Ajayi, A. and Owolabi, H.	2020	21
R19	Munaro, M., Fischer, A., Azevedo, N. and Tavares, S.	2019	16
R20	Charef, R. and Emmitt, S.	2021	13
R21	Nisbet, M.A., Marceau, M.L. and VanGeem, M.G.	2002a	13
R22	Gue, I., Promentilla, M., Tan, R. and Ubando, A.	2020	10
R23	Huuhka, S. and Hakanen, J.H	2015	10
R24	Morel, J. C. and Charef, R.	2019	9
R25	Du, L., Yu, L. and Cheng, R	2010b	9
R26	Andersen, S., Larsen, H., Raffnsoe, L. and Melvang, C.	2019	9
R27	Nordby, A.S.	2019	9
R28	Chang, Y.T. and HsiehS.H.	2019	9
R29	Guerra, B. and Leite, F	2021	6
R30	Peceño, B., Leiva, C., Alonso-Fariñas, B. and Gallego-Schmid, A.	2020	5
R31	Lei, J., Huang, B. and Huang, Y.	2020	5
R32	Balador, Z., Gjerde, M. and Isaacs, N.	2020	5
R33	Xueliang, Y., Mengyue, L., Qian, Y., Xiaohan, F., Yuqiang, T., Junhua, F., Qiao, M., Qingsong, W., and Jian, Z	2020	5
R34	Kledyński, Z., Bogdan, A., Jackiewicz-Rek, W., Lelicińska-Serafin, K., Machowska, A., Manczarski, P., Masłowska, D., Rolewicz-Kalińska, A., Rucińska, J., Szczygielski, T., Walczak, J., Wojtkowska, M. and Zubrowska-Sudol, M.	2020	4
R35	Gupta, S. and Chaudhary, S.	2020	4
R36	Al Hosni IS, Amoudi O. and Callaghan, N	2020	3
R37	Charef, R., Ganjian, E. and Emmitt, S.	2021	2
R38	Pitti, A., Espinoza, O. and Smith, R.	2020	2
R39	MacKenbach, S., Zeller, J. and Osebold, R.	2020	2
R40	Peñate-Valentín, M. C., Sánchez-Carreira, M. and Pereira, Á.	2021	1
R41	Bigolin, M., De Moura Ferreira Danilevicz, A. and L.C.P	2016	1
R42	Charef, R., Morel, J.C. and Rakhshan, K	2021	1
R43	Cruz Rios, F and Grau, D.	2020	0
R44	Cruz Rios, F., Grau, D. and Bilec, M.	2021	0
R45	Genc, O.	2021	0
R46	Rakhshan, K., Morel, J.C. and Daneshkhah, A	2021	0
R47	Shooshtarian, S., Maqsood, T., Wong, P.S.P., Khalfan, M. and Yang, R.	2021	0
R48	D'Alençon, R., De Leon, A., Saintard, R., Huerta, O. and Vásquez, C.	2020	0

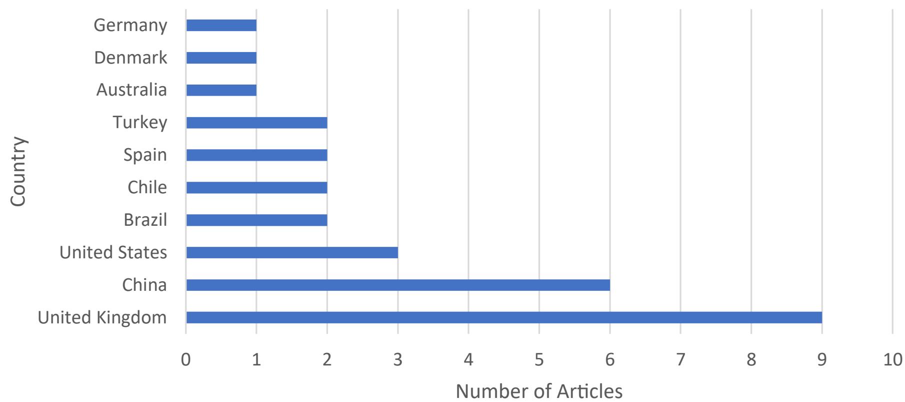
Source(s): Author(s) Construct, 2022

Table 1. List of publications reviewed



Source(s): Author(s) Construct, 2022

Figure 2.
Document by year analysis



Source(s): Author(s) Construct, 2022

Figure 3.
Document by country analysis of the top 10 countries

Scientometric analysis

To further appreciate the key issues within CE, the scientometric analysis was adopted. This was based on a science mapping approach. This approach focuses on imaging and domain analysis (Van Eck and Waltman, 2018). Several tools exist for undertaking the science mapping method such as Sci2Tool, Vantage Point and Leydesdorff's Software. The VOSViewer software was however selected for use. This is because, VOSViewer can envision, explore and develop bibliometric networks and maps (Van Eck and Waltman, 2018; Kukah *et al.*, 2022). In bibliometric analysis, it is relevant to explore the relationships between authors, citations, co-author analysis, co-word analysis and bibliographic coupling which can all be achieved using scientometric techniques such as the science mapping method (Cobo *et al.*, 2011).

For this study, the scientometric analysis was restricted to the co-occurrence of keywords although other methods of analysis could be carried out. The co-occurrence of keywords is useful for identifying knowledge gaps, "hot" topics and future research directions of research in any area. In this study, it helped establish the relevant knowledge gaps and status quo of research surrounding the barriers to CE uptake in the construction industry. Running the obtained data through the VOSViewer software produced a total of 1,917 keywords after which the minimum occurrence was set at 5, to avoid less important keywords. From this, 103 keywords met the threshold. The first ten most occurring and highly linked keywords generated from the software are tabulated in descending order of their links in Table 2.

These highly ranked keywords reveal the status quo of research surrounding the barriers to CE adoption in the construction industry. For instance, recent studies have identified the barriers to recycling (Guerra and Leite, 2021), control of construction waste and CDW management (Huang *et al.*, 2018), all within the built environment.

Visualizing the co-occurrence of the keywords generated by the software is best done with the Network Visualization tool in VOSViewer. This is shown in Figure 4.

In Figure 4, the size of the circles represents the occurrences of keywords. The larger a circle the more likely a keyword has been co-cited in the selected publications. The keywords "circular economy" and "sustainable development" had the strongest strength as depicted by the size of the circle and the distance between the keywords. This distance between keywords reveals relative strength and topic similarity. Also, circles in the same color cluster suggest similar topics among the publications.

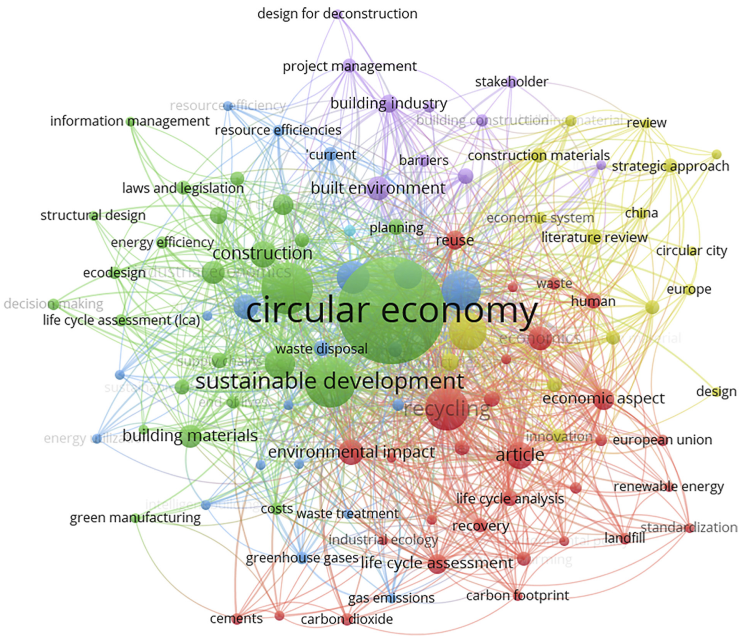
These keywords were also presented in an Overlay visualization which depicted the years within which the keywords were obtained. The overlay visualization allows for a better appreciation of the currency of the keywords being researched in the area of CE as it relates to the built environment. This overlay map reveals the "hot" or trendy themes of barriers to CE adoption within the construction industry. This is shown in Figure 5.

The color of the keywords shows the year trend of the keywords. The keywords appearing in yellow are the more current ones ranging from 2020 to 2021. The keywords in purple or blue are the older keywords that were used in publications before and up till 2019. An example of a current keyword is "Reuse", positing that current research on barriers to CE adoption within the built environment is focusing on the re-use of construction materials toward the elimination of waste. Grafstrom and Siri Aasma (2021) for instance, have revealed that one key barrier to CE adoption is the lack of knowledge on the re-use of CDW. Furthermore, the keyword "reuse" as it relates to the lifecycle of a building has been proposed to be considered in the design of buildings and not merely an afterthought at the demolition stage of the building (Charef *et al.*, 2021b). Similarly, the keyword "building" as it relates to

Keywords	Occurrences	Links
Circular economy	202	1111
Construction industry	63	474
Sustainable development	62	468
Recycling	49	455
Waste management	41	380
Demolition	31	306
Sustainability	38	284
Article	23	256
Life cycle	27	236
Environment impact	21	226

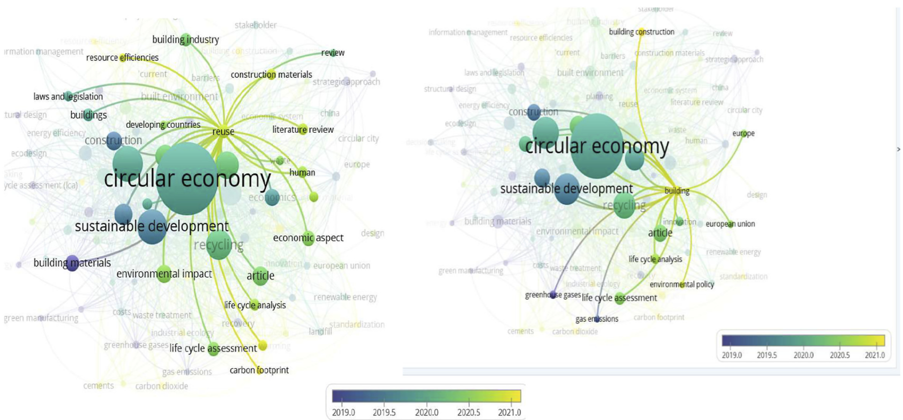
Source(s): Author(s) Construct, 2022

Table 2. Highest-ranked keyword occurrences



Source(s): Author(s) Construct, 2022

Figure 4.
Network visualization of co-occurring keywords



Source(s): Author(s) Construct, 2022

Figure 5.
Overlay visualization of keyword co-occurrence

"environmental policy" is a current theme in barriers to CE adoption within the construction industry positing that current environmental policies do not advocate for CE principles and thus creates a barrier to the successful adoption of CE into the construction industry. This has been advocated in the seminal works of Rakhshan *et al.* (2021) and Shooshtarian *et al.* (2021).

The content analysis followed the scientometric analysis to allow key themes and barriers to evolve from the review. The barriers identified in the 48 articles selected for comprehensive analysis were categorized to facilitate discussions. The choice of barrier categorization is in line with similar previous studies (Afful *et al.*, 2021; Ograh *et al.*, 2021). The names or labels for the barriers may be different but they essentially capture the same phenomena. For instance, Huuhka and Hakanen (2015) used four categories for their barriers namely, economic, social, ecological and technological. Rakhshan *et al.* (2021) added two more categories namely organizational and political barriers. Paletta *et al.* (2019) used Technical-technological, Legislative, Economic and Sociocultural barriers, whereas Kirchherr *et al.* (2018) used Technological, Regulatory, Market and Cultural Barriers. This is also similar to the six categories captured by Charef *et al.* (2021a, b) and the four categories proposed by Grafström and Aasma (2021). On this basis, this study subsumed the identified barriers under six main categories: Economic/Financial Barriers, Technical Barriers, Social Barriers, Cultural Barriers, Technological Barriers and Environmental Barriers.

The barriers and the source from which they were obtained are presented in Table 3, and ranked in order of appearance in literature to allow for a better appreciation of the identified barriers.

Results and discussion

All the 79 barriers were subsumed under six distinct categories as shown in Table 3. This categorization is an important finding of this research and contributes to the body of knowledge in the subject area. Barrier categorization facilitated the discussion of findings and the development of related solutions, providing implications and solutions for practice, society, and the industry as a whole.

Economic/financial barriers

The most occurring barriers identified under the Economic/Financial Barriers category were the high cost of reclaimed materials, low market value, low landfill cost, limited market supply and demand of reclaimed materials, budget and upfront cost, and design cost. This was evidenced in studies by Huang *et al.* (2018), Mahpour (2018), Campbell-Johnston *et al.* (2019) and Rakhshan *et al.* (2021). It was confirmed from the works of Charef *et al.* (2021b) and Tingley *et al.* (2017) that many professionals were of the view that additional cost was presented as the main obstacle impeding CE uptake. As seen in some studies (Nisbet *et al.*, 2002b; Kifokeris and Xenidis, 2021), the high costs accruing from the processing of waste contribute to the higher costs of reclaimed materials, thereby have been presented as an impediment to CE adoption. The high costs associated with reclaimed materials prevent clients from demanding these sustainable materials, as they invariably lead to higher material costs in building construction projects (Genc, 2021). This is seen in suppliers shunning away from such expensive materials, thus affecting the supply and demand of such materials. Again, as revealed by Tingley *et al.* (2017), the general lack of demand for composite construction in itself prevents building owners from venturing into construction material options that allow for the use of reclaimed materials. This barrier is further affected by the low market value of recovered or reclaimed materials (Campbell-Johnston *et al.*, 2019), borne from the perception of inferiority of such materials (Gupta and Chaudhary, 2020; Kledyński *et al.*, 2020) and the high costs of these reclaimed materials. Furthermore, the profit-focused nature of the construction industry (Grafstrom and Aasma, 2021) dissuades the recycling of demolishing waste when the costs of dumping at landfills are substantially lower. This is in direct relation to the lower costs of demolition, rather than deconstruction, toward the goal of re-using materials (Peceño *et al.*, 2020). The extra costs accruing from deconstruction prevent building owners and clients from seeking out this sustainable option. Other related economic/financial barriers such as the difficulty of reclaimed materials to break into established markets dominated by newly manufactured products inhibit market

Broad categories	Code	Barrier	Rate of occurrence	Author/Source
Economic/Financial Barriers (Ec/F B) (24)	Ec/F B1	High cost of reclaimed materials	10	R7, R16, R19, R21, R29, R33, R37, R36, R44, R45
	Ec/F B2	Low market value	10	R1, R2, R3, R6, R7, R16, R21, R33, R36, R44
	Ec/F B3	Low landfill cost	9	R2, R3, R6, R7, R9, R16, R21, R30, R45
	Ec/F B4	Limited market supply and demand	9	R2, R3, R7, R16, R19, R21, R36, R38, R42
	Ec/F B5	Design cost	8	R6, R7, R15, R16, R19, R36, R44, R45
	Ec/F B6	Budget and upfront cost	8	R1, R4, R7, R16, R26, R31, R36, R45
	Ec/F B7	Duration and labor cost	8	R3, R7, R16, R19, R21, R36, R38, R44
	Ec/F B8	Cost of approach	7	R1, R3, R7, R16, R18, R19, R21
	Ec/F B9	Market of recovered materials	7	R3, R7, R16, R19, R21, R36, R46
	Ec/F B10	Access to finance	7	R6, R7, R15, R16, R19, R36, R37
	Ec/F B11	Material cost	7	R1, R4, R6, R7, R15, R16, R19
	Ec/F B12	Difficulty to break into the established markets dominated by industrial materials	7	R2, R3, R6, R7, R16, R36, R44
	Ec/F B13	Market and business prefer advantage demolition rather than deconstruction	7	R2, R6, R7, R16, R28, R34, R36
	Ec/F B14	Low cost of CDW disposal	6	R2, R5, R6, R16, R19, R36
	Ec/F B15	Low cost of virgin materials relative to secondary ones	6	R6, R7, R9, R14, R16, R36
	Ec/F B16	Lack of competition	5	R6, R7, R16, R21, R36
	Ec/F B17	Client readiness to pay for extra	6	R1, R7, R16, R19, R31, R37
	Ec/F B18	Less manpower and more mechanization	5	R2, R3, R7, R16, R21
	Ec/F B19	Estimation challenge	5	R7, R19, R29, R36, R33
	Ec/F B20	Insurance cost	5	R7, R16, R19, R36, R44
	Ec/F B21	Additional construction cost for reclaimed and recycle materials	5	R1, R7, R29, R36, R41
	Ec/F B22	Lack of incentives and defined benefits	5	R3, R6, R7, R33, R36
	Ec/F B23	Immature recycling market operation	4	R2, R3, R6, R16
	Ec/F B24	Profit seeking first	3	R14, R16, R21
Technical Barriers(TB) (20)	TB1	Design codes focusing on reclaimed materials is limited	12	R2, R3, R6, R8, R11, R16, R17, R29, R33, R34, R46, R40
	TB2	Lack of building design standards for reducing CDW	11	R2, R3, R6, R8, R11, R16, R18, R19, R26, R34, R40
	TB3	Lack of policy incentives	10	R3, R6, R7, R8, R16; R17; R18, R19; R36, R38
	TB4	Lack of regulations and implementation guidelines	9	R2, R3, R6, R7, R16, R17, R18, R19, R26
	TB5	Prohibitive domestic policy	9	R3, R6, R8, R11, R16, R19, R33, R38, R25

(*continued*)

Table 3.
Categorized barriers impeding CE uptake

Broad categories	Code	Barrier	Rate of occurrence	Author/Source
	TB6	Lack of green designing of construction projects	9	R2, R3, R6, R7; R8, R16, R17, R40, R42
	TB7	Lack of storage facility for reclaimed materials and access to the site	9	R2, R3, R4, R5, R6, R7, R19, R29, R33, R37, R39
	TB8	Poor skills of operatives related to construction waste reduction and treatment.	8	R3, R6, R16, R17, R19, R33, R36, R37
	TB9	Prohibitive international policy	8	R3; R6, R8, R11, R16, R17, R19, R38
	TB10	Lack of information about existing structure and materials	7	R2, R7, R8, R11, R16, R19, R36
	TB11	Lack of design standards in existing regulations	7	R2, R3, R6, R16, R17, R19, R33
	TB12	Lack of equilibrium in recycling and reuse marker	7	R2, R3, R6, R7, R16, R19, R33
	TB13	Lack of data related to CDW generation for policy decision making	6	R2, R3, R6, R16, R18, R19
	TB14	Lack of guidance for effective CDW collection and sorting	6	R2, R3, R8, R11, R16, R33
	TB15	Inadequate policies and legal frameworks to manage CDW as well as lack of supervision on CDW management	6	R3, R6, R16, R18, R33, R34
	TB16	Improper urban planning	5	R2, R3, R16, R19, R46
	TB17	Inherent complexity of transforming to circular economy in CDW management	5	R2, R6, R16, R19, R36
	TB18	Lack of mature and complete municipal regulation system to guide CDW	5	R2, R3, R6, R16, R19
	TB19	Lack of government support	5	R2, R3, R6, R16, R19
	TB20	Lack of CE marking strategies	4	R3, R16, R19, R28
Social Barriers(SB) (11)	SB1	Lack of awareness, knowledge and understanding on environmental impact of polluted waste and pollution of virgin feedstock.	12	R1, R2, R6, R7, R9, R10, R12, R18, R19, R28, R36, R35
	SB2	Lack of demand in composite construction	10	R2, R3, R6, R8, R11, R16, R17, R19, R36, R38
	SB3	Lack of education on CE strategies among stakeholders	9	R1, R2, R7, R12, R18, R19, R36, R37, R41
	SB4	Society evolution	7	R1,R6, R16, R19, R21, R36, R41
	SB5	Lack of client demand	7	R2, R3, R7, R16, R19, R36; R37
	SB6	Market preparedness	6	R3, R7, R16, R19, R21, R36
	SB7	Construction sector inertia	5	R36, R19, R41, R16, R7
	SB8	Low image placed on individuals who use reclaimed and recycled materials	5	R6, R16, R19, R22, R36
	SB9	Unrealistic hypothesis	4	R36,R19,R34,R16
	SB10	Aesthetic trend	3	R1,R19, R36
	SB11	Strong belief that waste management is more expensive	2	R30, R36

(*continued*)

Table 3.

Broad categories	Code	Barrier	Rate of occurrence	Author/Source
Cultural Barriers(CB) (15)	CB1	Lack of concern for reclaimed materials	12	R7, R9, R14, R16, R20, R21, R22 R23, R28, R36, R37, R44
	CB2	Lack of trust and acceptance of reclaimed materials	12	R3, R9, R14, R16, R18, R19, R20, R21, R22, R23, R28, R36
	CB3	Lack of trust in data	11	R9, R14, R16, R18, R19, R20 R21 R22, R28, R29, R33, R43
	CB4	Consumer society: consumer culture and perceptions for reclaimed materials	10	R7, R9, R14, R16, R20, R21, R22, R23, R36, R44
	CB5	Perception of second-hand materials being sub-standard	10	R1, R6, R9, R14, R16, R19, R21, R22, R23, R36
	CB6	Lack of global vision	9	R1, R3, R7, R14, R16, R21, R19, R23, R36
	CB7	Lack of collaboration and value chain thinking	9	R1, R3, R7, R16, R18, R23, R24, R28, R38
	CB8	Cultural beliefs	8	R9, R14, R16, R20, R21, R22, R23, R36
	CB9	Hesitance to CE integration and business models	8	R6, R7, R14, R16, R23, R28, R33, R36
	CB10	Resistance to change of old generation	8	R6, R7,R14,R16, R18, R21, R23, R36
	CB11	Lack of empirical based literature on the barriers	7	R8, R6, R16, R28, R29, R33, R43
	CB12	Preference for off-site CDW sorting/ landfilling over on site sorting due to lack of incentives	7	R2, R6, R9, R16, R22, R23, R30
	CB13	User preference for new construction materials over reused/ recycled ones	7	R1, R7, R9, R16, R21, R22, R28
	CB14	Ingrained linear mindset	6	R1, R6, R7, R13, R16, R21, R36
	CB15	Culture of waste behavior-assumption that waste is inevitable	2	R33, R36
Technological Barriers(TechB) (5)	TechB1	Lack of performance guarantees for reused materials	6	R2, R3, R6, R16, R31, R32
	TechB2	Lack of own technology to recover and reuse materials by managers	5	R2, R3, R6, R7, R16
	TechB3	Lack of producer-based responsibility system in production of construction materials	5	R1, R6, R16, R32, R35
	TechB4	Insufficient application of the 3R approach by construction practitioners and projects	4	R2, R6, R7, R16
	TechB5	Immature recycling technology	4	R2, R3, R6, R16
Environmental Barriers(EnB) (3)	EnB1	Lack of environmental protection in construction waste management.	8	R3, R6, R7, R25, R28; R33; R37, R38
	EnB2	Lack of incentives on environmental assessment methods	7	R6, R7, R16, R25, R28, R33, R38
	EnB3	Environmental impact: emission from transport, use of virgin feedstock	6	R6, R16, R25, R27, R38, R40

Table 3.

Source(s): Author(s) Construct, 2022 entry for such materials (Rakhshan *et al.*, 2021). This is to say, the market prefers to spend on newly manufactured products rather than "second-hand" or reclaimed materials, preventing the entry of these recycled or reclaimed materials. Finally, cost estimation challenges at the design and even deconstruction phases, and higher costs of experts to be employed on such projects, prevent the smooth uptake of CE in the construction industry (Al Hosni *et al.*, 2020).

Addressing economic/financial barriers

The economic/financial barriers can be addressed through sensitization fora for the promotion of reclaimed materials. The fora will educate on the durability, cost–benefit and quality of reclaimed and recycled materials (Grafstrom and Aasma, 2021). This will address the low market value and ignorance of benefits and gains from reclaimed or recycled materials. Again, the creation of online platforms and marketplaces for reclaimed materials and deconstruction projects will allow for easier market penetration of reclaimed or recycled materials (Nordy, 2019). Providing a readily available platform could bridge the gap between demand and supply, while overcoming the extra costs of reclaiming materials (Gue *et al.*, 2020; Charef and Emmitt, 2021; Charef *et al.*, 2021b). Despite, the extra cost implication of reclaimed materials, it is believed that stakeholders in the construction industry are more likely to embrace the concept of CE if they are better informed about the benefits CE presents (Pitti *et al.*, 2020). Furthermore, increasing the costs of landfill disposal would deter the excessive dumping of waste and allow for the move toward re-using materials in construction works.

Technical barriers

Under this category, limited design codes focusing on reclaimed materials, lack of building design standards for reducing CDW and lack of policy incentives (Veleva *et al.*, 2017; Ghisellini *et al.*, 2018; Gupta and Chaudhary, 2020; Kledynski *et al.*, 2020; Rakhshan *et al.*, 2021) were seen as the highest-occurring barriers. Some studies have shown that there is scanty information as to how buildings can be designed using reclaimed materials (Campbell-Johnston *et al.*, 2019; Charef and Emmitt, 2021). Few European countries have come out with design codes, standards, prohibitive domestic and international policies, and guidelines to aid in using reclaimed materials for construction works (Mahpour, 2018). Also, the lack of policy incentives on circular product usage as well as limited green design strategies are some of the key barriers impeding the uptake of CE in the construction industry (Ghisellini *et al.*, 2018). It is worth noting that Tingley *et al.* (2017) identified the lack of a storage facility for reclaimed materials as one major barrier in their research work. Guerra and Leite (2021) hold the view that providing a storage facility for reclaimed materials will promote the market of reclaimed materials to be used in the construction industry.

From the design phase, some studies (Chileshe *et al.*, 2018; Munaro *et al.*, 2019; Yuan *et al.*, 2020) have emphasized the design of buildings without consideration for the building's disposal. This prevents the successful reclaiming of building materials (Munaro *et al.*, 2019). Again, the lack of technical knowledge on the deconstruction process and limitations due to the space available to store reclaimed materials has often been cited as a barrier to CE uptake (Veleva *et al.*, 2017; Wu *et al.*, 2019; Yuan *et al.*, 2020). As a complex process, the notion of deconstruction should be incorporated into the design phase of buildings by the introduction of deconstruction experts to ensure the possibility of reclaiming materials (Morel and Charef, 2019). This is borne from design codes that should focus on deconstruction processes and subsequently the reduction of CDW. The lack of policies, design standards and guidance for effective CDW management has often been cited as impediments to CE uptake in the construction industry (Huuhka and Hakanen, 2015).

Addressing technical barriers

To address the technical barriers to CE uptake, the focus should be on the development of building codes centered on deconstructing buildings and standards for reclaiming material (Penate-Valentin *et al.*, 2021). Updating current building codes for new construction to allow for the introduction of reclaimed materials in new construction projects would open up the market's acceptance of reclaimed materials (Huang *et al.*, 2018). Strict building policies of construction waste management would compel professionals to seek CE training and expertise, adopt CE principles, increase the use of reclaimed or recycled materials and generally reduce CDW (Al Hosni *et al.*, 2020).

The lack of data on the use of reclaimed materials presents a knowledge gap in the area of CE uptake, which can be solved by increased research focus on the properties and benefits of reclaimed materials. Generally, the identified barriers in this category are best curbed by the need to have CE implementation guidelines for strict adherence by construction professionals.

Social barriers

From Table 3, some of the highest-ranked barriers in the Social Barriers category are the lack of awareness, knowledge, and understanding of CE practices, lack of demand in composite construction, lack of education on CE strategies among stakeholders, society evolution and lack of client demand (Hosseini *et al.*, 2015; Tingley *et al.*, 2017; Mahpour, 2018; Gue *et al.*, 2020; Charef *et al.*, 2021a). Moral and Charef (2019) in their empirical study ranked the lack of education on CE strategies among stakeholders as a key barrier to the implementation of CE. Similarly, Chileshe *et al.* (2015) highlighted the lack of understanding and awareness of CE practices as a major hindrance to CE uptake in the construction industry. The above results also corroborate findings from Pitti *et al.* (2020) who indicated that the knowledge and awareness levels of the impact of polluted waste and demolished waste on the environment are quite low. It is therefore not surprising that these barriers have been ranked as the most occurring Social Barriers in this study. Other top-ranking barriers are lack of client demand as well as low level of market preparedness. These barriers are also highlighted in similar works by Häkkinen and Belloni (2011) and Charef *et al.* (2021b).

Furthermore, the user preference for new construction materials over re-used ones has prevented the easy market penetration of reclaimed materials. This is further propounded by the state of the market preparedness to accept reclaimed materials (Huang *et al.*, 2018). The bad image of recycled and reclaimed materials and the current aesthetic trends of construction designs (Charef *et al.*, 2021a) have prevented the uptake of CE principles. Successful uptake of CE depends highly on the perception and preference for the use of reclaimed materials by building owners (Charef *et al.*, 2021b). It is argued that the inability of the industry to accept change is attributed to the traditional knowledge of always using virgin construction materials (Mahpour, 2018).

Addressing social barriers

Many of the social barriers captured can be addressed by awareness, knowledge and understanding of the need for the uptake of reclaimed materials and reused materials through public education. Stakeholders in the construction industry must ensure that society's perception that secondhand materials are substandard is erased. This can be achieved by continuous education and training on the use of reclaimed materials (Charef *et al.*, 2021a), ensuring that reclaimed construction materials are made aesthetically attractive (Hakkinen and Belloni, 2011; Charef *et al.*, 2021a), and leadership by example where key professionals and stakeholders and the state set good examples by demonstrating their use of reclaimed materials in their building projects. Once this is done it will help drive the preparedness of the market for the use of reclaimed materials.

Cultural barriers

Lack of concern for reclaimed items, lack of trust and acceptance of reclaimed materials, lack of trust in data, consumer culture and perception for reclaimed materials, perception of second-hand materials being sub-standard, lack of global vision, lack of collaboration, and value chain thinking were the topmost barriers identified under this category.

Cultural beliefs are intertwined in the uptake of new methods and the uptake of CE is no exemption. The lack of a global vision for waste reduction is directly correlated with linear rather than circular thinking, and general ignorance of life-cycle thinking (Tingley *et al.*, 2017; Ghisellini *et al.*, 2018). These have been often cited as an impediment to CE uptake in the construction industry. The hesitance to CE integration and business models related to the poor market for reclaimed materials and the related high costs of reclaimed materials (Nisbet *et al.*, 2002b) have also been presented as cultural barriers. Furthermore, the ingrained perception that waste generation is inevitable is in-line with false beliefs surrounding CE principles in the construction industry (Lei *et al.*, 2020). As posited by Al Hosni *et al.* (2020), the lack of empirical-based research on reclaimed materials and the consumer culture for reclaimed materials are all cultural impediments that ought to be addressed. Moreover, the skepticism and preference for traditional or conventional construction methods lead to a natural resistance to change from building owners and construction professionals alike (Chileshe *et al.*, 2018). Finally, the preference for off-site CDW sorting over on-site sorting results in the loss of reclaimed materials and the build-up of waste (Huuhka and Hakanen, 2015; Kledynski *et al.*, 2020). Overcoming the barrier of lack of trust in data as well as collaboration and value chain thinking must be a major priority for stakeholders (Nisbet *et al.*, 2002b; Huuhka and Hakanen, 2015; Charef *et al.*, 2021a).

Addressing cultural barriers

Concern for reclaimed materials can be increased through continuous education on the negative environmental effects of excessive use of raw materials and their impact on the economy as a whole. Building trust in data for reclaimed materials can be promoted by government agencies who will be responsible for highlighting the strength and quality of reclaimed materials through the publication of research data and findings. Furthermore, the use of reclaimed materials in government building projects would increase trust in the benefits and use of reclaimed materials (Charef *et al.*, 2021a).

Again, eliminating the false perception that massive waste generation on construction sites is inevitable would propel the uptake of CE principles. Good education of construction professionals on ways to avoid waste generation during and after construction would help curb this barrier. A global vision for the use of reclaimed materials can be achieved through collaborative efforts by all stakeholders involved. To promote collaboration and value chain thinking, all stakeholders and construction professionals must be involved to develop a roadmap that will promote the use of reclaimed materials in the construction industry.

Technological barriers

From Table 3, lack of performance guarantee for reused materials, lack of own technology to recover and reuse construction materials by stakeholders, immature recycling technology, lack of producer-based responsibility system in the production of construction materials, insufficient application of the 3R approach by construction practitioners and projects, and immature recycling market, appeared to be the most occurring Technological Barriers globally (Huang *et al.*, 2018; Mahpour, 2018; Campbell-Johnston *et al.*, 2019; Pitti *et al.*, 2020). Some of these barriers were also highlighted in the works of Charef *et al.*, (2021) when they indicated that there is little information on how materials can be recycled and little information on what technology to use to promote recycled materials. Also, several authors are of the view that the current regulation in their countries is quite strict hindering innovation, i.e. the 3R approach (Reduced, Reused and Recycle) (Huang *et al.*, 2018; Mahpour, 2018). Many of the technological barriers identified in the literature are related to the lack of appropriate tools, technology and procedures to recover or reuse materials (Gupta and Chaudhary, 2020; Pitti *et al.*, 2020). The immature recycling technology available has been cited to prevent construction managers from having to recycle their materials (Kifokeris and Xenidis, 2017). This emanates from technology that is not well-advanced enough to properly recycle materials and the lack of technology that would otherwise have promoted efficient deconstruction (Gupta and Chaudhary, 2020). This has invariably led to excessive loss of reclaimed material value.

Addressing technological barriers

The development of technology that would efficiently reclaim demolished materials would aid in curbing this barrier. As a knowledge gap identified, there is a lack of research focus on the development of technology and processes to reclaim demolition waste. Investment support from government and private partners to develop such affordable, easy-to-use and accessible technology for recycling and reclaiming CDW is proposed to curb the technological barriers identified. Furthermore, a strict quality assurance standard on reclaimed materials would provide buyers with the needed assurance on the durability and quality of reclaimed materials produced. Again, increasing knowledge awareness and educating all stakeholders on the use of the 3R (Reduced, Reused, and Recycle) approach to promote the uptake of reclaimed materials must be considered.

Environmental barriers

The most occurring environmental barriers in Table 3 are lack of awareness of environmental protection through construction waste management, lack of incentives on environmental assessment methods, and environmental impact of emission from transport and use of virgin feedstock (Wu *et al.*, 2019; Guerra and Leite, 2021; Charef *et al.*, 2021a; Charef and Emmitt, 2021). These studies indicated that the above barriers have consistently proved to be the concern of most stakeholders across the globe in the implementation of CE in the construction industry, hence the need to address them.

As seen in this study, the environmental barriers are less prominent and this is corroborated with findings from Charef *et al.* (2021b). This, they say, is because authors usually limit the environmental barriers to the EOL phase of the building project and thus processing reclaimed materials at the EOL is more an economic problem than an environmental one. Notwithstanding, the waste generated is an environmental issue because they end up in landfills creating environmental problems (Pitti *et al.*, 2020). This is directly linked to the lack of awareness of environmental protection through construction waste management and the lack of incentives for environmental assessment methods (Wu *et al.*, 2019; Guerra and Leite, 2021). Very few studies have also identified that the transport of new materials creates emissions, although all such issues have been identified as economic barriers in some studies (Andersen *et al.*, 2019; Charef *et al.*, 2021b). This is attributed to the profit-focused nature of the construction industry.

Addressing environmental barriers

The public needs to be educated on the environmental impact of construction projects in terms of emissions from the transport of materials, CDW and virgin feedstock usage as a first step to curtail this problem. Furthermore, construction workers need to be provided with an incentive package that encourages them to follow the environmental assessment procedures diligently. Finally, reclaimed materials must be stored in facilities that make them more accessible and attractive.

Interrelationships among the barriers to CE uptake in the construction industry

The interrelationship among the barriers impeding the uptake of CE is represented in Figure 6. This interrelationship established among the barriers allows for a better conceptualization of the impact of each barrier on another. This important finding is often downplayed in existing literature as identified barriers are viewed as independent of each other. Exploring the interrelationship among the barriers would not only reveal the impact of each barrier on the other but also aid in the proposal of salient solutions that can mitigate the interdependent barriers identified.

An important finding of this study revealed that the majority of the barriers to CE uptake in the construction industry were economic/financial barriers. The highest-ranked barriers

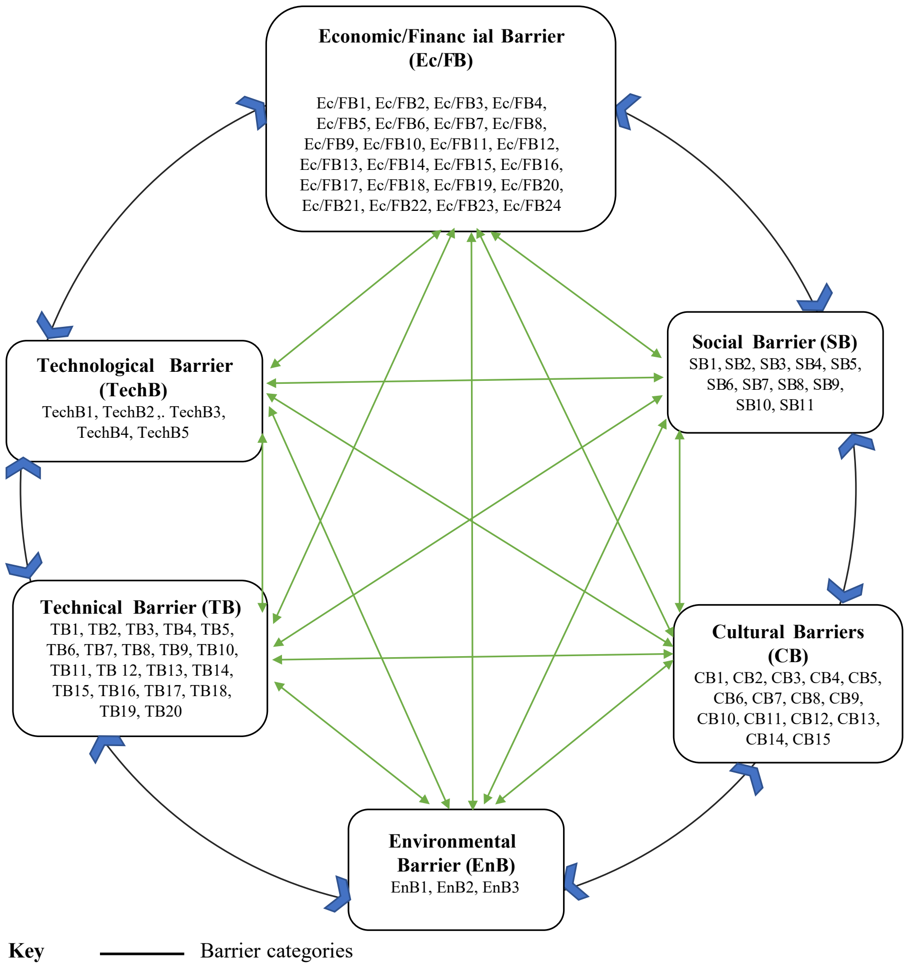


Figure 6.
Conceptual framework of CE

were identified as the high cost of processing reclaimed materials into market-ready materials (Ec/F B1). This, in addition to the overall increased cost of construction materials (Ec/F B12; Ec/F B9; Ec/F B22), dissuades clients from venturing into the market for reclaimed materials (Ec/F B18). These economic/financial barriers can be attributed to the immature technology (TechB5) and unavailability of own technology (TechB2) that would allow for the cheaper processing of reclaimed materials. Being a technological barrier, the development of such technology is dependent on investor support (private and/or public) to fund such novel projects. The lack of investor support can be attributed to the lack of concern for reclaimed materials (CB1) identified as a cultural barrier.

Generally, there is a lack of awareness and understanding of CE practices (SB1) and the perception of second-hand materials as sub-standard (CB5). These Social and Cultural barriers are borne from the lack of concern for reclaimed materials (CB1) and the lack of trust and acceptance of reclaimed materials (CB2) subsumed under Cultural Barriers. The lack of trust and acceptance for reclaimed and recycled materials (CB1; CB2) comes as a result of a knowledge gap identified by this study as the lack of sufficient data on the properties of reclaimed and recycled construction materials. As a cultural barrier, this was expounded on by Charef *et al.* (2021a) who indicated that the lack of trust in the viability of reclaimed materials (CB3) causes low market value for reclaimed materials (Ec/F B2). The cultural barrier of resistance to change (CB10) to adopt CE principles and reclaimed materials is stringent on the lack of trust in the reclaimed materials (CB2), the lack of performance guarantees for materials (TechB1), and a general lack of knowledge and expertise on CE approaches (SB 1). This in turn affects the market supply and demand for reclaimed materials (Ec/F B4) and thus the difficulty of entry into existing established construction markets (Ec/F B13).

Furthermore, an empirical study by Cruz-Rios and Grau (2020) indicates that some construction industry professionals find it difficult to ensure that construction materials are recovered in the appropriate manner, due to the lack of expertise (TB8). This lack of expertise comes as a result of little to no training because many professionals cannot appreciate the impact of construction waste on the environment (SB1; EnB3). Without due appreciation of the effect of construction waste on the environment (SB1), building policies, codes, standards and guidelines, would not consider CE principles (TB1; TB2; TB4; TB15), thus preventing professionals from acquiring the needed expertise, knowledge and skills in CE (TB8). Ordinarily, when professionals are aware of a concept, they will ensure that the right design codes are drafted for its use. Similarly, the poor application of the 3R approach by construction practitioners and projects (TechB4) comes from the lack of expertise in the area of CE on construction sites (TB8) and the low client demand for buildings with CE principles (TB10). The low costs of dumping refuse in landfills (Ec/F B14) are correlated with the lack of awareness of the impact of construction waste on the environment (SB1). These interrelationships could go on and on with one leading to the other within categories and across categories. These are only to highlight a few of such relationships toward the development of the framework.

Similar to the interrelationship among the barriers is the interrelationship among their solutions proposed. For instance, the proposed solution of providing training and education to professionals on the impact of waste generation on sites and its effect on the environment can combat several barriers. This would increase the market value of reclaimed materials, allow for funding of own technology to reclaim materials and push for the incorporation of CE principles into building codes. Availability of this technology would allow for cheaper costs in processing CDW, thus reducing costs of reclaimed materials. Education and awareness would also eliminate the perception that mass waste generation on construction sites is unavoidable and allow for the introduction and uptake of CE principles on construction projects and the demand for CE experts and trained professionals. Furthermore, researching and publishing data on the durability, properties, performance and benefits of reclaimed materials would build trust in these materials and eliminate perverse thinking about the inferiority of these materials. This would afford the easy penetration of reclaimed materials into the existing market and a higher demand for these materials. All such proposed solutions, like the identified barriers, are interdependent.

Framework development

A framework is thus proposed based on the interrelationships identified among the categories of the barriers. The framework was developed based on the conceptualization of the individual barriers. This is in line with frameworks developed by similar literature review studies (Pomponi and Moncaster, 2017; Charef *et al.*, 2021b; Ograh *et al.*, 2021; Afful *et al.*, 2021, 2022). The interrelationships shown in the framework graphically represent the discussion of findings identified from the literature, in this study. The framework could inform and enable integrated strategies to address the barriers holistically.

For easy appreciation, the categories of the barriers are shown in the framework. The peripheral solid arrows represent the interrelatedness of major categories of barriers identified in the study. This relationship has been established in the prior discussion. The inner lines stress the interrelationship of practical links between the identified barriers and barrier categories. This interconnectedness is identified as a sub-relationship among the barriers.

Practical implications of the study

By examining barriers to CE uptake in the construction industry, the study builds on the existing theoretical work in this field of study. In terms of contributing to practice, the study could serve as a valuable source of information for policymakers and practitioners in the construction industry on how to integrate CE. The study has proposed possible strategies to address the barriers identified in the study. In addition, this study has highlighted the interrelationship among the various barrier categories in a framework, to provide a platform for identifying the interconnectivity of barriers, and hence, possible integrated strategies to holistically overcome the barriers. The literature review also identified key research gaps such as the lack of research data on the properties of reclaimed materials in construction. This allows for the direction of future research studies in CE within the built environment.

Conclusion and future research

The research sought to present a comprehensive literature review that focused on the identification of barriers inhibiting CE uptake in the construction industry. The aim was to identify the barriers in the literature and classify them into broad categories. Subsequently, the study sought to identify knowledge gaps, current research trends and propose practical solutions to combat the identified barriers to CE uptake in the construction industry. In the quest to accomplish this, 48 relevant articles from peer-reviewed journals and published conference proceedings were reviewed to identify 79 barriers impeding CE uptake in the construction industry. Lack of awareness and understanding of CE practices, perception of second-hand materials as substandard, lack of trust and acceptance of reclaimed materials, inadequate market value, and limited design code focusing on reclaimed materials are a few of the barriers identified. The identified barriers were grouped into six categories, namely Social, Cultural, Economic/Financial, Technological, Technical and Environmental Barriers based on similar review studies (Pomponi and Moncaster, 2017; Charef *et al.*, 2021b) on CE within the built environment.

Following the identification and categorization of barriers, the study developed a framework showing the interrelationships among the barrier categories. The framework reveals the interconnectedness of the identified barriers.

The findings of this study are not geographically limited and therefore provide a global perspective on barriers to the uptake of CE in the construction industry. The highly occurring barriers identified in this study, and the framework developed, offer valuable information for stakeholders in the construction industry to enhance their understanding and knowledge of what priority barriers to address for the uptake of CE within the construction industry. The scientometric review undertaken allowed for the appreciation of “hot” themes, research gaps and the status quo of research in barriers to CE uptake. For instance, “hot” themes on barriers to CE uptake in the construction industry surround the keyword “re-use” as it relates to the “building industry” and “construction materials”. Similarly, “environmental policy” as it relates to “building construction” projects was identified as a current research area on barriers to CE uptake in the construction industry.

Future research should be directed to finding strategies to help curb CE barriers and bridging knowledge chasms or gaps identified. A key knowledge gap identified was the lack of research data on the properties of reclaimed CDW materials. Bridging this gap would mean curbing the barrier of trust in the durability of these reclaimed materials, erasing perverse perceptions of the reclaimed materials and thus allowing for its easy entry into established markets for construction materials. Other key areas for further studies should focus on the identification of appropriate and low-cost technologies for reclaiming used materials, and framework development for CDW management. It is also recommended that research be conducted to assess the market potential for reclaimed, recycled or reused materials, performance guarantee for reused materials, and finally application of the 3R approach by construction practitioners and projects.

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Corresponding author
Safowaa Osei-Tutu can be contacted at: osafowaa@yahoo.com