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Benjamin I. Oluleye, Daniel W.M. Chan, Timothy O. Olawumi, Abdullahi B. Saka

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Assessment of symmetries and asymmetries on barriers to circular economy adoption in the construction industry: A survey of international experts

*****Benjamin I. OLULEYE
benjamin.oluleye@connect.polyu.hk
Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong
*Corresponding author

Daniel W.M. CHAN
daniel.w.m.chan@polyu.edu.hk
Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong,

Timothy O. OLAWUMI
t.olawumi@napier.ac.uk
School of Computing, Engineering and the Built Environment, Edinburgh Napier University, Edinburgh, Scotland, United Kingdom

Abdullahi B. Saka
a.saka@leedsbeckett.ac.uk
School of Built Environment, Engineering and Computing, Leeds Beckett University, Leeds, United Kingdom

Abstract

This study evaluates simultaneously the symmetries and asymmetries on the classification of barriers to circular economy (CE) adoption in the building construction industry (BCI) of developing and developed economies. This is crucial because the vagueness of the impacts of CE barriers in extant studies affects encyclopaedic and specific CE policy formulation. Consequently, feedbacks from 140 CE experts across 39 developing and developed economies were analysed. Fuzzy synthetic evaluation (FSE) was deployed to objectively determine the significant impacts of the barriers, whereas the Mann-Whitney *U* test was applied to identify significant differences in experts' opinions between the two economies. The FSE results indicated that organizational, information technology, and infrastructures and logistics barriers are the most critical to global CE adoption. The Mann-Whitney *U* test reveals a significant difference in the experts' perspectives between developing and developed economies on regulatory, information technology, and economic and market barriers. Therefore, they are perceived as specific barriers as they impact CE adoption in BCI differently across the two

economies. However, infrastructure and logistics, and organizational barriers are classified as general barriers. The findings of this study underscored the contextuality of barriers to CE adoption in BCI and demonstrated the need for generic and specific policy development. Also, the significance indices of the classification of the barriers using FSE serve as an allocative function that will help policymakers and stakeholders allocate requisite resources to the most profound barriers to achieving global systemic circularity and zero construction waste.

Keywords: Barriers; Building construction industry; Circular economy; Fuzzy Synthetic Evaluation.

1. Introduction

A significant number of materials in the building construction industry (BCI) today are designed for and managed in a linear economy. This implies that crude materials are extracted, processed through manufacturing, used for as long as they are needed, and disposed of at their end of life (Oluleye et al., 2022a). This linear pattern causes different intergenerational and intergovernmental concerns like waste disposal in a landfill and resource depletion (Upadhyay et al., 2021b; Oluleye et al., 2022b). Circular economy (CE) has emerged as a counter-initiative to the linear production and consumption patterns in the BCI (Kirchherr et al., 2018). It offers a new lens for valuing resources through slowing, narrowing, and closing loops of production and consumption path. It engineers a restorative paradigm through principles of design for disassembly, recycling, recovery, and reuse (Joensuu et al., 2020).

BCI has become a top priority in the transition to a CE due to its ecological footprint(Wuni, 2022). Nevertheless, the attainment of global responsible consumption and production through CE in BCI is complicated because of contradictory challenges (Mahpour, 2018). The contradictions are evident in the different prioritization attached to the barriers, which has affected CE policy development. Interestingly, the barriers militating CE adoption in BCI are being prioritized inconsistently among experts in developing and developed countries (Oluleye et al., 2022b).

Studies in developing countries have identified certain barriers to CE adoption in the BCI while in developed economies, a different set of barriers have also been highlighted (Guerra, 2021; Giorgi et al., 2022). However, established CE policies for the BCI that are exclusively built around the views of either developing countries or developed economies to tackle the barriers are vitiated and contrariwise. Typical examples of policy inadequacies are demonstrated by (Heurkens & Dąbrowski, 2020; Yu et al., 2022).

Therefore, without assessing the circularity challenges from both developing and developed economies' perspectives, policymakers would continue to be bedevilled with inequitable information, which could result in a skewed circularity action plan and policies. The existing CE action plan has failed to reduce over 10 billion BCDW (building construction and demolition waste) annually across the globe. The United States generates over 700 million tonnes of waste, while Europe generates over 820 million tonnes (Chen & Lu, 2017), and an estimated 2.36 billion is generated in China (Ding et al., 2021).

Furthermore, stakeholders in developed and developing economies are making efforts to enable CE development toward zero BCDW. Despite these efforts, barriers such as regulatory, information technology, infrastructure, and logistics, economic and market, and organizational barriers still hamper the successful implementation of CE in BCI (Oluleye et al., 2022a). These barriers bedevil both developing and developed economies unequally. Thus, to enhance the all-inclusive, and specific policies for CE toward zero BCDW, it is important to understand the symmetries and asymmetries in the barriers groups to CE adoption from an international perspective so as guide policies development and resource allocation. Therefore, this study evaluates the perspectives of CE experts in the BCI from developing and developed economies on a set of major barriers to CE adoption toward zero waste. Notwithstanding the policy divergence among countries, research from a comparative perspective would have practical implications for policymakers worldwide. The findings of this study increase the understanding of barriers that require specific policies and those that require all-inclusive policies toward CE development in BCI. It also advocates a contextualist perspective and underscores the need to be context-conscious in pushing global policies for CE adoption.

2. Systemic circularity implementation barriers in the BCI

The barriers that hamper stakeholders' CE adoption in BCI demand different attention for effective CE policy implementation (Giorgi et al., 2022). Existing studies have categorized the various barriers that could hamper CE adoption in BCI into a controllable size. In the USA, Cruz Rios et al. (2021) highlighted economic, technical, and regulatory barriers as the categories of barriers to circular building design, but weights weren't attached to the barrier groups. Bilal et al. (2020) classified the barriers to CE in BCI into regulation, awareness, institutional and financial in 16 developing countries. The study captured the relationships among the barriers but failed to prioritize the groups of barriers identified. Hence, equal weights were attached to the barriers group. Yet the study advocated for institutional support for CE. Using a review lens on the barriers to CE in BCDW, Oluleye et al. (2022b) unveiled major barrier categories which include regulatory, information technology, infrastructure and logistics, economic and market, and organizational barriers. The relationship between the barriers was only conducted without a clear understanding of the priorities of the various groups. Wuni (2022) further adopted a review approach to identify the barriers to circular construction, and the findings complement (Oluleye et al., 2022). Yet Wuni (2022) still advocated for regulatory and economic-related barriers based on the frequency of citations, which could be biased and subjective. Therefore, the barriers groups identified and validated in previous studies were adopted in this study since they represent various management dimensions of CE in BCI and encompass many of the barrier groupings in other extant studies.

Priority attachment to these groups of barriers from the perspective of developing and developed countries is still ambiguous and too subjective in extant studies, which could affect resource allocation and policy implementation for CE adoption. Despite this, information technology advancement has been advocated in advancing CE adoption. This is attested in the 2022 circularity gap report, in which most enabling approaches were tailored to address digital data-driven and information-related issues militating CE development, especially in the BCI (Circle Economy, 2022). Policy attention has been on the technology and information dimensions. However, policies for ameliorating other quadruple institutional and regulatory, infrastructure and process, economic and market, and organizational barriers to CE adoption in BCI toward zero BCDW are skimpy. BCI's global attention to digital and information circularity is because BCI is the least digitized sector. Hence, a concerted effort toward digital circularity could change the narrative in the BCI. Likewise, attention to information sharing is necessary because sufficient access to information on a product and the operations of other actors can enhance the material in a loop system.

Regardless of the advocacy for information technology, studies have posited that the cost implication of acquiring the needed technology and developing the secondary market is on the high side (Adams et al., 2017; Condotta & Zatta, 2021). This could scare practitioners and other experts from investing in CE adoption. Hence, this challenge could be tagged as economic and market barriers. (Oluleye et al., 2022b). For example, lack of financial commitment for CE adoption, lack of market for secondary products, and buyers' perception of secondary products as being inferior have been noted as critical economic and market barriers to CE adoption in BCI (Jin et al., 2017; Ratnasabapathy et al., 2021b). As a result, economic and market underlying barriers are considered very critical to CE adoption over information and technology in such studies.

However, among the five categories of barriers, other studies have considered infrastructure and logistics barriers as the most critical to CE adoption toward zero BCDW. Studies by (Mahpour, 2018; Giorgi et al., 2022), revealed that until a benchmarking circular process and infrastructure are in place, it will be difficult to enhance zero BCDW in the BCI. Therefore, infrastructure and logistics barriers such as lack of tracking mechanism, lack of circular network among experts, and inadequate facilities for sorting and monitoring systems are the critical barriers to CE adoption in the BCI. Hence, with these barriers in place, it will be difficult to manage the pattern of materials and product flow, making effective CE adoption difficult from the beginning of life to the end of life of materials in the BCI.

Nevertheless, studies have revealed that some entrenched issues in the BCI could limit the development of CE adoption. These barriers could be ascribed to organizational barriers. For instance, organizational barriers such as entrenched business-as-usual patterns, BCI fragmentation, and poor commitment of the practitioners to CE adoption have been identified as major factors retarding the adoption of CE in the BCI. Qualitative studies by Giorgi et al. (2022) in five developed countries showed that an effective business model to create, capture, and deliver value toward improved resource efficiency by extending the lifespan of products and parts, thereby realizing environmental, social, and economic benefits is still lacking. Therefore, effective organizational development has a strong impact on CE development toward zero waste.

Moreover, studies have also revealed that CE adoption is hampered by regulatory barriers. For instance, Huang et al. (2018) discovered that low acceptance of CE in the BCI toward zero BCDW is related to regulatory issues. Regulatory barriers could be attributed to inadequate CE guidelines and standards, weak legislation for CE adoption, lack of government certification for value capture and recovery, and existing building codes that do not support secondary materials. Thus, studies have established that regulatory issues are limiting the adoption of CE in BCI (Mahpour, 2018; Liu et al., 2021a).

Studies reviewed showed that there exists unanimity on the prioritization of the major classification of barriers to CE in BCI. The reason for this could be that the barriers to CE adoption in BCI are economies-dependent (developed or developing) and the opinion of stakeholders on the barriers might differ across the two economies. Hence, to enhance the adoption of CE from a developing and developed economies perspective, a group of major barriers with their criticalities must be analysed. This will provide a better lens and unprejudiced information for better policy development and resource allocation to tackle the more critical issues of CE development.

Further, the interrelationships and qualitative approaches adopted for assessing the barriers in extant studies provide an intriguing view of the barriers. As such, Adabre et al. (2022a) advised against erroneously capturing subjectivity in outcomes while doing such analyses. Aside from the fact that studies reviewed for this current research did not carry out a simultaneous evaluation of the barriers to CE adoption toward zero BCDW from the perspective of developed and developing nations, there also exist scarce studies that investigated and evaluated the barriers to CE adoption toward zero BCDW objectively and quantitatively to eliminate fuzziness in respondents' opinion. These identified gaps in research give the basis upon which this study conducted a statistical difference analysis together with the objective evaluation of the fuzziness associated with the groups of barriers (Table 1) to CE adoption from developing and developed countries BCI.

Table 1: Barriers to systemic circularity implementation towards zero BCDW adapted from (Oluleye et al., 2022b)

Classification of barriers	Code	Underlying barriers	References
Regulatory (RE)	RE1	Lack of circularity guidelines for end-of-life collection and sorting of materials toward value creation	(Huang et al., 2018; Kirchherr et al., 2018)
	RE2	Lack of regulatory pressure and stringent penalties on dumping at the landfill	(Rios et al., 2021; Shooshtarian et al., 2022)
	RE3	Lack of supportive building codes for secondary materials	(Mahpour, 2018; Akinade et al., 2020)
	RE4	Lack of standard on the quality of refurbished and remanufactured products.	(Huang et al., 2018; Liu et al., 2021a)
	RE5	Lack of government promotion and commitment to design for disassembly	(Akinade et al., 2020; Liu et al., 2021a)
	RE6	Legislations for BCDW circularity are not binding	(Rios et al., 2021; Shooshtarian et al., 2022)
Information Technology (TE)			

	TE1	Lack of clearly defined CE indicators and metrics	(Hossain et al., 2020; Ramos & Martinho, 2021)
	TE2	The infancy of digital tools for circularity from the beginning of life to the end of life and beyond system boundary	(Ormazabal et al., 2018; Ayçin & Kayapinar Kaya, 2021)
	TE3	Unavailability of disassembly information for demolition auditing	(Akanbi et al., 2020)
	TE4	Unavailability of effective web-based waste exchange systems and databases for the quality of secondary products	(Ajayi et al., 2015; Ratnasabapathy et al., 2021b)
	TE5	Lack of effective CE-based knowledge management systems among stakeholders	(Mahpour, 2018; Shooshtarian et al., 2022)
	TE6	Unavailability of BCDW data for prediction in a CE environment	(Mahpour, 2018)
	TE7	Lack of systemic circularity education and training for supply chain members	(Kirchherr et al., 2018; Mahpour, 2018)
Infrastructure and logistics (IL)			
	IL1	Lack of BCDW sorting and recovery infrastructure	(Mahpour, 2018; Akanbi et al., 2020)
	IL2	Lack of benchmarking process for CE adoption	(Rios et al., 2021; Liu et al., 2021a)
	IL3	Lack of comprehensive reverse logistic networks and facilities	(Kirchherr et al., 2018; Hartwell et al., 2021)
Economic and market (EM)	EM1	Lack of capital and financial resources for CE	(Liu et al., 2021a; Shooshtarian et al., 2022)
	EM2	Virgin materials are cheaper than secondary materials	(Udawatta et al., 2015)
	EM3	Lack of market mechanisms for waste recovery	(Akinade et al., 2020)
	EM4	Lack of market demand for second-hand materials	(Ranta et al., 2018; Ratnasabapathy et al., 2021a)
	EM5	Lack of high-quality secondary products (i.e low value of materials at end of life)	(Huang et al., 2018; Liu et al., 2021a)
Organizational (OG)	OG1	Fragmented nature of BCI and its supply chain network	(Dunant et al., 2017; Kanters, 2020)
	OG2	Inadequate organizational effort in the development of a circular business model	(Huang et al., 2018)
	OG3	Inadequate organizational resources and capabilities to support CE principles	(Mahpour, 2018; Shooshtarian et al., 2022)
	OG4	Lack of top management support and leadership toward circular design	(Huang et al., 2018)

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3. Methods

3.1 Research design and approach

This study adopted a quantitative research design grounded on positivist epistemology with experts serving as the basis for assessing the symmetry and asymmetry of the barriers. Further, a multistage methodological approach consisting of a literature review, expert pilot interview, questionnaire design and administration, and data pretesting and analysis was initiated. These stages are summarised in Fig. 1.

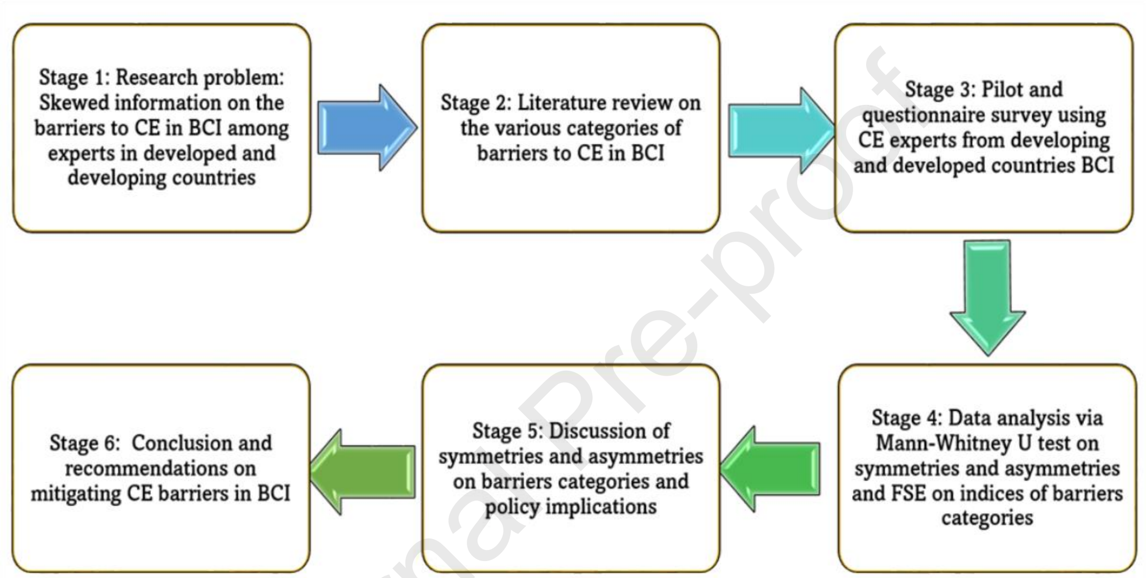

Figure 1: Research framework for the study

A total of 25 barriers to CE adoption in BCI were derived and classified into five groups and employed in developing an empirical questionnaire. Part A of the survey form solicited the background characteristics of the experts while part B requested the experts to assess the level of significance of the barriers on a 5-point Likert scale (1-Not significant,… 5-Very significant). The 5-point Likert scale of measurement is employed because it does not overload the respondent with options, allows a lower error margin, can capture the respondent's view with adequate interpretation, and has been employed in related studies (Saka et al., 2022). Purposive sampling was employed to identify and select experts from the industry and academia with expertise in CE and waste management. Emails with a weblink for the survey were sent to 420 identified experts. 277 responses were received out of which 140 responses (from 39 developing and developed economies) were deemed suitable for this analysis after data cleaning. Although the sample size is small, it is above the minimum threshold of 30 responses required for the Central Limit Theory to make a credible conclusion.

3.5 Respondents' profile

The profile distribution of the experts is summarized in Table 2. The experts are from diverse locations and professional backgrounds with the majority having over 11 years of experience, which aligns with the aim of this study. Thus, these experts are appropriate to evaluate the barriers to CE in BCI. Additionally, the responders had substantial years of CE experience in the BCI.

Table 2: Respondents' profile

Categories	**Attributes**	**Economies**	
		Developing F (%); 79(56.43)	**Developed F (%); 61(43.57)**
Continents distribution	Africa	36(25.72)	
	Asia	60(42.86)	
	Europe	29(20.71)	
	North America	7(5.00)	
	South America	4(2.86)	
	Australia	4(2.86)	
Type of organization	Public client	8(10.1)	14(23.0)
	Private client	14(17.7)	7(11.5)
	Project consultant	12(15.2)	5(8.2)
	Main contractor	6(7.6)	13(21.3)
	Trade contractor	1(1.3)	2(3.3)
	Academic and research institutions	38(48.1)	20(32.8)
Years of working experience in the BCI	1-5 years	22(27.8)	5(8.2)
	6-10 years	22(27.8)	7(11.5)
	11-15 years	10(12.7)	15(24.6)
	16-20 years	15(19.1)	10(16.4)
	> 20 years	10(12.7)	24(39.3)
Years of CE-related experience	1 year	42(53.2)	31(50.8)
	2 years	15(19.0)	13(21.3)
	3 years	8(10.1)	6(9.8)
	4 years	2(2.5)	5(8.2)
	>4 years	12(15.2)	6(9.8)

Note: F= frequency, %= percentage frequency

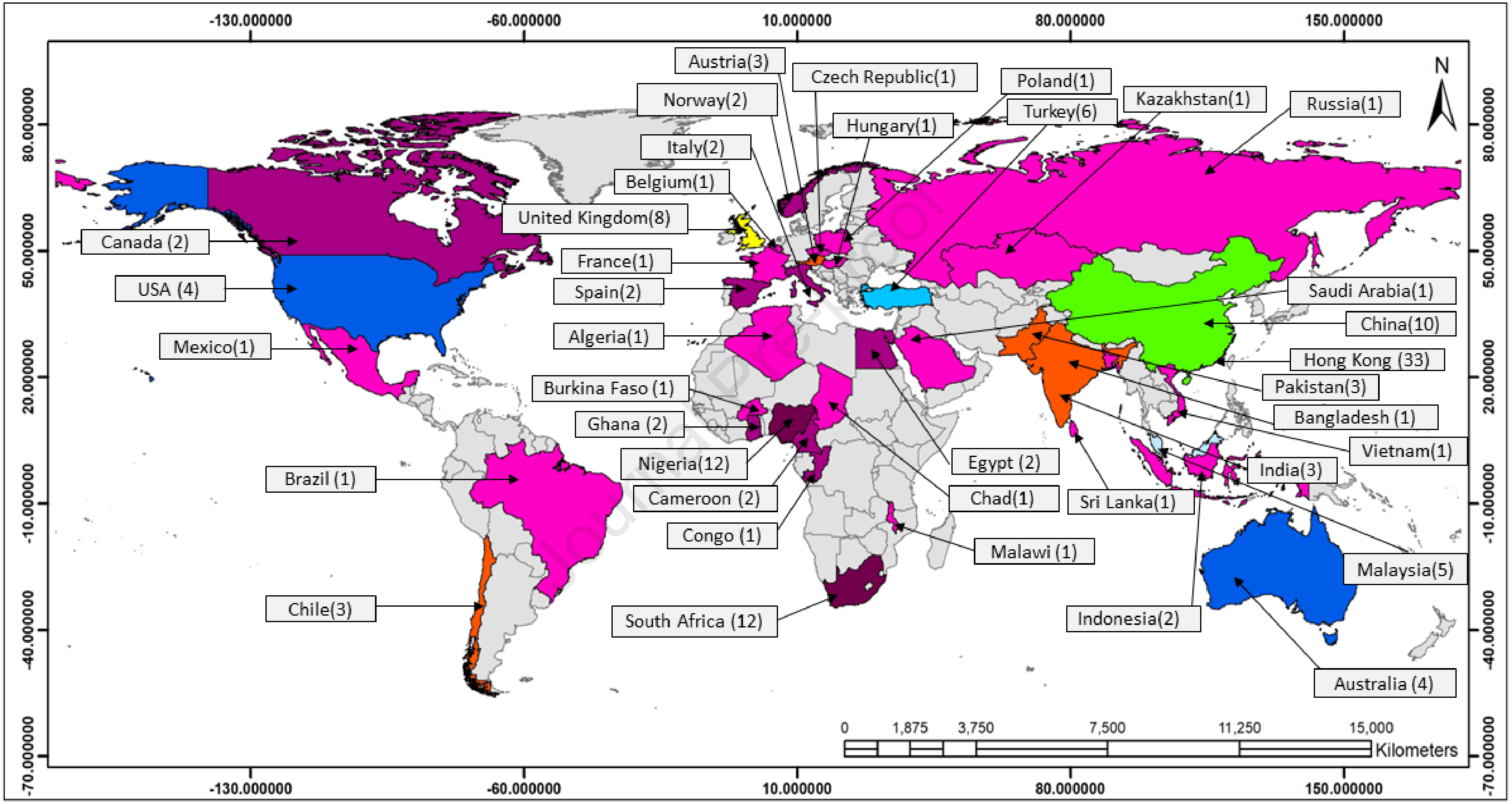

Figure 2: Locations of the chosen experts from developing and developed economies

3.6 Data analysis

Cronbach's Alpha was used to evaluate the internal consistency of the responses and the data reliability. Cronbach's Alpha for the 25 barriers was 0.964 and 0.940 for developing and developed countries respectively. Although the value is greater than 0.90, the survey form is not long as it contains 25 items, hence the constructs are discriminately valid (Tavakol & Dennick, 2011). The Shapiro-Wilk test was conducted to ascertain normality in the data distribution, based on the null hypothesis that the sample is normally distributed. This resulted in a 0.05 significance level, suggesting that the data was not normally distributed. Consequently, non-parametric tests are employed in analyzing the data.

3.6.1 Descriptive statistical analysis

The barriers to CE adoption in BCI were initially assessed using descriptive statistical analysis which includes mean and standard deviation. The mean analysis results were deployed as the basis for conducting the Mann-Whitney *u* test and for assigning indices to the barrier categories using the fuzzy synthetic evaluation (FSE) approach.

3.6.2 Mann-Whitney U test

Moreover, to examine the significant difference in the opinions of the two groups (developing and developed countries) investigated in this study, independent sample t-test, Wilcoxon signed-rank test, and Mann Whitney *U* test could be adopted as demonstrated in extant studies (Pham et al., 2021; Almohassen et al., 2022; Adabre et al., 2022a). However, using these methods requires different conditions. Mann Whitney *U* test, a non-parametric test is appropriate when the dependent variable is either ordinal or continuous, but not normally distributed. It is very flexible as the number of respondents in the representative groups can be varied. This technique was adopted for comparing the means of the two independent groups on a set of barriers to CE adoption in BCI since the data are not normally distributed (MacFarland & Yates, 2016). The Mann-Whitney *U* test was conducted at a significance level of 0.05 to test the null hypothesis (there is no significant difference between the means of the barriers to CE adoption for the two sets of respondents). Further, the Mann-Whitney *U* test influences the result obtained in this study as it gives a true reflection of the characteristics of the data, which invariably makes the findings and conclusions drawn credible and reliable relative to other statistical methods.

3.6.3 Fuzzy synthetic evaluation (FSE) method

The FSE analysis was adopted to objectively quantify the barriers categories to CE adoption. It is appropriate as it can accommodate fuzziness in expert responses on multicomponent barriers by converting linguistic scale into a fuzzy number, which will eventually enable objective determination of the FSE significance indices for the categories of barriers to CE adoption in BCI (Adabre et al., 2022a). This study, therefore, adopted a five-stage FSE approach to determine the significant indices of the barriers as established by (Xu et al., 2010; Adabre et al., 2022b). Comprehensive details of the FSE calculations are presented in the *Appendix.*

3.6.3.1 Fuzzy synthetic evaluation index development

In developing the index system, two levels were established, which are the first and second levels. The first level constitutes the five main classifications of the barriers: regulatory (RE), information technology (TE), infrastructures and logistics (IL), economic and market (EM), and organizational (OG). The underlying barriers under each classification represent the second level. For instance, {*RE1, RE2, RE3, RE4, RE5, and RE6}C* are the underlying barriers under the regulatory (RE) barriers category.

Therefore, the index system for the classification of the barriers and the underlying barriers is expressed as: RE = {*RE1, RE2, RE3, RE4, RE5, RE6*}, TE = {*TE1, TE2, TE3, TE4, TE5, TE6, TE7*}, IL = {*IL1, IL2, IL3*}, EM = {*EM1, EM2, EM3, EM4, EM5*}, and OG = {*OG1, OG2, OG3, OG4*}. The developed index system constitutes the input parameters for the FSE operation. The rating scale used for the assessment of the criticalities of the barriers was defined as Ҷ = {1, 2, 3, 4, 5}, denoting the set of grade alternatives of the scale comprising Ҷ$_1$(Not significant), …Ҷ$_5$(Very significant).

3.6.3.2 Computing the weightings of the barriers and the classification of the barriers to CE adoption in BCI

In this stage, the weightings of the underlying barriers and the classification of the barriers were calculated through the normalization of their mean values. These were computed using equation 1, expressed as:

$$W_i = \frac{\mu_i}{\sum_{i=1}^{5} u_i},\ 0 < w_i < 1, \text{ where } \sum_{i=1}^{5} w_i = 1 \qquad (1)$$

Where W_i= weights of underlying barriers or classification of the barriers, μ_i=mean values of barriers or summation of the mean values of the classification of the barriers.

3.6.3.3 Computation of the membership functions (MF) of the underlying barriers to CE in BCI

This stage encompasses the computation of the MFs for the underlying barriers. The MFs were initially conducted for the second level before the computation of the MF for the first level. The MFs of the second level are obtained from the expert's ranking of the underlying barriers via the questionnaire survey. For instance, given that B_{1TE2} is the percentage of the responses per each rating on the barrier, then the membership function of MF_{TE2} (*infancy of data-driven digital tools for circularity) could be illustrated using equation 2 as:*

$$MF_{TE2} = \frac{B_{1TE2}}{Ҷ_1} + \frac{B_{2TE2}}{Ҷ_2} + \frac{B_{3TE2}}{Ҷ_3} + \frac{B_{4TE2}}{Ҷ_4} + \frac{B_{5TE2}}{Ҷ_5} \quad (2)$$

3.6.3.4 Computation of the membership function (MF) of the classification of the barriers to CE in BCI

Having determined the MF of the underlying barriers, the MF of classification of the barriers (Di) was computed using equation 3 which is the product of the fuzzy matrix of the MFs (M_i) of its underlying barriers and the weighting function of the underlying barriers under each classification.

$$Di = W_i * M_i = (d_{i1}, d_{i2}, d_{i3}, \ldots, d_{in}) \quad (3)$$

Where, W_i = (w1, w2, w3, …, wn)

3.6.3.5 Determining the criticalities/significance indices of the classification of the barriers

Having determined the MF at level 1, the criticality and indices of each of the classifications of the barriers are determined which is the principal motive for the FSE analysis. Each significance index is calculated as the product of the fuzzy evaluation matrix (Di) and the rating scale (Ҷi). Equation 4 was adopted to determine each of the classifications of the barriers criticalities for developing and developed countries together with the overall significance indices for the classification of the barriers.

$$\text{Significance index} = \sum_{i=1}^{n} (D_i \times Ҷ_i) \quad (4)$$

For example, the significance index of *information technology barriers* (SI_{TE}) based on the developing county perspective could be illustrated as:

$$SI_{TE} = (D_{TE} \times Ҷ_i) = (D_{TE1}, D_{TE2}, D_{TE3}, D_{TE4}, D_{TE5}) \times (Ҷ_1, Ҷ_2, Ҷ_3, Ҷ_4, Ҷ_5)$$

Where, D_{TE} = fuzzy evaluation matrix or first-level membership function and $Ҷ_i$ =grade alternatives (1, 2, 3, 4, 5).

4. Analytical Results

4.1 Results of mean score analysis and Mann-Whitney U test on the barriers to CE in BCI

The barriers to CE adoption in BCI were ranked using their respective mean values and standard deviations as detailed in Table 3. For two barriers with equal values, the one with the lower standard deviation is prioritized higher. Regarding the developing countries, the mean values of the barriers range from 4.36 to 3.64 while for mean values for the developed countries range from 4.30 to 3.43. This result suggests that all the 25 barriers to CE in BCI captured in this study are quite significant in developing and developed countries.

Moreover, among the 25 barriers under investigation, experts from developing and developed countries prioritize the *inadequate organizational effort to the development of a circular business model (OB2)* as the most critical toward the development of CE in the BCI with mean values of 4.36 and 4.30 respectively. Further, the *lack of systemic circularity education and training for supply chain members (TE7)* was ranked second by the developing and developed countries with mean values of 4.25 and 3.85, respectively. Also, both groups ranked *unavailability of disassembly information for demolition auditing* as the third most critical barrier with mean values of 4.11 and 3.82. Despite this similar rating, the impact of the barriers based on the significant difference between the two groups is unique.

The outcome of the significant difference test between developing and developed countries' views on the barriers is presented in Table 3. The Mann-Whitney *U* test showed that one *regulatory barrier (lack of standard on the quality of refurbished and remanufactured products)* has a significant ρ-value < 0.05 and Z -value of -3.025. Regarding the *information technology barriers,* three barriers *(unavailability of effective web-based waste exchange systems and databases for the quality of secondary products, lack of effective CE-based knowledge management systems among stakeholders, and lack of systemic circularity education and training for supply chain members all have significant* test values < 0.05. On *infrastructure and logistic barriers*, one barrier (*lack of benchmarking process for CE adoption)* has a significant ρ-value < 0.05. *Economic and market barriers* have three underlying barriers (*lack of capital and financial resources for CE, virgin materials are cheaper than secondary materials, and lack of markets and demand for second-hand materials)* with significant test values < 0.05. Regarding *organizational barriers,* one barrier (*inadequate organizational resources and capabilities to support CE principles) has* a ρ-value < 0.05. The

Mann-Whitney *U* test result indicates that the impact and criticalities of some barriers are different in developing and developed economies. These outcomes further emphasize the need to objectively investigate the barriers to CE from developing and developed countries simultaneously to avert the issues related to skewed information and its spill-over impact on policy development. This is also important to understand barriers that need specific attention and those that need generic attention.

Table 3: Mean prioritization and Mann-Whitney U test of the barriers to CE adoption in BCI

Code	**Classification of barriers and the underlying barriers**	**Developing economies**			**Developed economies**			**Mann-Whitney *U* test**		
		μ_i	δ	Rank	μ_i	δ	Rank	U statistics	Z	ρ-value
RE- Regulatory barriers										
RE1	Lack of circularity guidelines for end-of-life collection and sorting of materials toward value creation	4.00	.796	8	3.71	1.189	9	2138.500	-1.200	0.230
RE2	Lack of regulatory pressure and stringent penalties on dumping at the landfill	3.80	.963	22	3.66	1.218	13	2359.500	-0.218	0.827
RE3	Lack of supportive building codes for secondary materials	3.84	1.019	21	3.52	1.239	24	2087.500	-1.403	0.161
RE4	Lack of standard on the quality of refurbished and remanufactured products.	3.98	.940	11	3.58	1.069	18	1723.500	-3.025	0.002*
RE5	Lack of government promotion and commitment to design for disassembly	3.89	1.034	17	3.76	1.100	4	2278.500	-0.575	0.565
RE6	Legislations for BCDW circularity are not binding	3.84	1.003	20	3.72	1.132	7	2282.000	-0.560	0.575
IT- Information Technology barriers										
IT1	Lack of clearly defined CE indicators and metrics	3.97	.875	14	3.70	1.113	10	2117.500	-1.309	0.190
IT2	The infancy of digital tools for circularity from the beginning of life to end of life and beyond system boundary	3.97	.856	13	3.63	1.146	16	2052.500	-1.582	0.114
IT3	Unavailability of disassembly information for demolition auditing	4.11	.915	3	3.82	1.118	3	2245.500	-.730	0.465

IT4	Unavailability of effective web-based waste exchange systems and databases for the quality of secondary products	4.07	.854	5	3.57	1.106	20	1767.500	-2.844	0.004*
IT5	Lack of effective CE-based knowledge management systems among stakeholders	4.10	.831	4	3.68	1.057	11	1920.000	-2.249	0.025*
IT6	Unavailability of BCDW data for prediction in a CE environment	3.97	.836	12	3.63	1.100	15	2029.500	-1.688	0.091
IT7	Lack of systemic circularity education and training for supply chain members	4.25	.994	2	3.85	1.122	2	1861.000	-2.466	0.014*
IL-Infrastructure and logistic barrier										
IL1	Lack of BCDW sorting and recovery infrastructure	3.75	.943	24	3.75	1.149	5	2340.000	-0.305	0.761
IL2	Lack of benchmarking process for CE adoption	4.05	.939	6	3.63	1.200	17	1937.000	-2.117	0.034*
IL3	Lack of comprehensive reverse logistic networks and facilities	4.00	.931	10	3.72	1.061	6	2037.000	-1.673	0.094
EM-Economic and Market Barriers										
EM1	Lack of capital and financial resources for CE	3.89	.985	16	3.52	1.131	23	1953.500	-2.019	0.043*
EM2	Virgin materials are cheaper than secondary materials	3.79	.897	23	3.58	1.326	19	1875.500	-2.340	0.019*
EM3	Lack of market mechanisms for waste recovery	3.64	1.141	25	3.53	.985	22	2253.000	-0.682	0.495
EM4	Lack of markets and demand for second-hand materials	4.05	1.007	7	3.57	1.140	21	1812.000	-2.639	0.008*
EM5	Lack of high-quality secondary products (i.e low value of materials at end of life)	3.89	1.050	19	3.71	1.156	8	2216.500	-0.850	0.396
OG- Organizational barriers										
OG1	Fragmented nature of BCI and its supply chain network	4.00	.913	9	3.65	1.177	14	2042.500	-1.615	0.106
OG2	Inadequate organizational effort in the development of a circular business model	4.36	.857	1	4.30	.897	1	2345.500	-0.298	0.766

OG3	Inadequate organizational resources and capabilities to support CE principles	3.89	1.034	17	3.43	1.237	25	1905.500	-2.218	0.027*
OG4	Lack of top management support and leadership toward circular design	3.93	.892	15	3.66	1.175	12	2146.000	-1.167	0.243

Note: Test of significance: * $\rho < 0.05$

4.2 Significance indices of the classification of the barrier to CE in BCI using the FSE approach

Based on the established five stages for the FSE analysis of the barriers to CE in BCI conducted in section 3.6.3, the weightings and membership function of the underlying barriers and the classification of the barrier were computed. This informed the computation of the significance indices for the barrier groups. Table 4 provides a summary of the weightings of the underlying barriers and the classification of the barrier. The weightings for the various classifications of barriers for developing and developed countries were not used in ranking because they are sensitive to the number of underlying barriers within each classification which could be skewed toward the classification with the higher number of barriers. Further, the MFs of the underlying barriers and the classification of the barriers to CE in BCI from developing and developed economies are also summarised in Table 4. The MFs were adopted in computing the significance indices/criticalities of the classification of the barrier to CE in BCI (see section 3.6.3.5). The results of the significances indices for the barriers classifications are illustrated as follows:

Recall equation 4,

Significance index=$\sum_{i=1}^{n}(D_i \; x \; Ч_i)$

Therefore, the significance indices for regulatory barriers to CE in BCI in developing countries are presented:

SI_{RE} = (0.02, 0.06, 0.20, 0.44, 0.28) × (1, 2, 3, 4, 5) = 3.90

A similar approach was adopted to compute the FSE of other barrier groups for both developing and developed economies. The FSE results are presented in Table 5. Also, the Mann-Whitney *U* test on the significant difference in the classification of the barriers between developing and developed countries is detailed in Table 5.

Table 4: Weightings and membership functions of the underlying barriers and the classification of barriers to CE in BCI

Classification /underlying barriers	**Code**	**Developing economies**			**Developed economies**		
		Wi	**MF for level II**	**MF for level I**	**Wi**	**MF for level II**	**MF for level I**
RE-Regulatory		**0.236**			**0.238**		
	IR1	0.171	(0.02, 0.02, 0.16, 0.56, 0.24)	(0.02, 0.06, 0.20, 0.44, 0.28)	0.169	(0.08, 0.05, 0.29, 0.29, 0.32)	(0.06, 0.08, 0.27, 0.32, 0.28)
	IR2	0.163	(0.02, 0.08, 0.23, 0.43, 0.25)		0.167	(0.06, 0.11, 0.24, 0.27, 0.32)	
	IR3	0.164	(0.03, 0.05, 0.26, 0.36, 0.30)		0.160	(0.08, 0.14, 0.24, 0.28, 0.27)	
	IR4	0.170	(0.03, 0.05, 0.10, 0.54, 0.28)		0.163	(0.06, 0.06, 0.29, 0.39, 0.19)	
	IR5	0.167	(0.02, 0.08, 0.25, 0.31, 0.34)		0.171	(0.05, 0.08, 0.22, 0.38, 0.28)	
	IR6	0.164	(0.03, 0.07, 0.18, 0.44, 0.26)		0.169	(0.06, 0.04, 0.32, 0.28, 0.30)	
TE-Information Technology		**0.287**			**0.282**		
	TE1	0.140	(0.02, 0.05, 0.15, 0.53, 0.26)	(0.02, 0.03, 0.15, 0.46, 0.33)	0.143	(0.06, 0.08, 0.20, 0.42, 0.24)	(0.05, 0.09, 0.20, 0.40, 0.25)
	TE2	0.140	(0.02, 0.03, 0.18, 0.51, 0.26)		0.140	(0.05, 0.13, 0.22, 0.35, 0.25)	
	TE3	0.145	(0.02, 0.02, 0.21, 0.34, 0.41)		0.148	(0.05, 0.06, 0.23, 0.33, 0.33)	
	TE4	0.143	(0.02, 0.00, 0.20, 0.44, 0.34)		0.138	(0.05, 0.13, 0.23, 0.39, 0.20)	
	TE5	0.144	(0.02, 0.05, 0.08, 0.56, 0.30)		0.142	(0.05, 0.10, 0.15, 0.51, 0.19)	
	TE6	0.140	(0.02, 0.02, 0.21, 0.49, 0.26)		0.140	(0.05, 0.10, 0.24, 0.38, 0.23)	
	TE7	0.149	(0.03, 0.05, 0.05, 0.38, 0.49)		0.149	(0.06, 0.06, 0.14, 0.43, 0.30)	
IL-Infrastructure and logistics		**0.119**			**0.121**		
	IP1	0.318	(0.02, 0.07, 0.30, 0.39, 0.23)	(0.03, 0.04, 0.18, 0.46, 0.29)	0.338	(0.05, 0.09, 0.24, 0.34, 0.32)	(0.07, 0.05, 0.23, 0.40, 0.26)
	IP2	0.343	(0.03, 0.03, 0.11, 0.49, 0.33)		0.327	(0.11, 0.03, 0.20, 0.43, 0.23)	
	IP3	0.339	(0.03, 0.03, 0.13, 0.51, 0.30)		0.335	(0.06, 0.04, 0.24, 0.43, 0.23)	
EM-Economic and market		**0.194**			**0.195**		
	EM1	0.202	(0.05, 0.02, 0.20, 0.48, 0.26)	(0.03, 0.07, 0.23, 0.43, 0.26)	0.197	(0.08, 0.09, 0.27, 0.38, 0.19)	(0.07, 0.09, 0.25, 0.36, 0.23)
	EM2	0.197	(0.02, 0.05, 0.30, 0.44, 0.21)		0.200	(0.10, 0.11, 0.22, 0.24, 0.33)	
	EM3	0.189	(0.02, 0.18, 0.25, 0.26, 0.30)		0.197	(0.01, 0.15, 0.29, 0.38, 0.17)	
	EM4	0.210	(0.03, 0.07, 0.20, 0.44, 0.26)		0.199	(0.09, 0.06, 0.23, 0.43, 0.19)	

	EM5	0.202	(0.03, 0.02, 0.18, 0.53, 0.25)		0.207	(0.08, 0.05, 0.24, 0.35, 0.28)	
OG-Organizational		**0.163**			**0.164**		
	OB1	0.247	(0.02, 0.02, 0.26, 0.36, 0.34)	(0.02, 0.03, 0.17, 0.41, 0.36)	0.243	(0.09, 0.04, 0.28, 0.33, 0.27)	(0.07, 0.08, 0.23, 0.34, 0.34)
	OB2	0.269	(0.02, 0.02, 0.10, 0.33, 0.54)		0.286	(0.01, 0.01, 0.18, 0.25, 0.54)	
	OB3	0.240	(0.03, 0.08, 0.15, 0.44, 0.30)		0.228	(0.11, 0.10, 0.22, 0.38, 0.19)	
	OB4	0.243	(0.03, 0.02, 0.18, 0.53, 0.25)		0.243	(0.05, 0.14, 0.19, 0.34, 0.28)	

Table 5**:** FSE values and Mann-Whitney U test on significant differences in the classification of barriers to CE in BCI

Classification of barriers to CE in BCI	**Developing economies**		**Developed economies**		**Mann-Whitney U test**		
	FSE weights	**Rank**	**FSE Weight**	**Rank**	**U statistics**	**Z**	**ρ-value**
SI_{RE}-Significance indices of regulatory barriers to CE adoption in the BCI	3.90	4	3.71	4	21.000	-2.887	0.002*
SI_{TE}-Significance indices of information technology barriers to CE adoption in the BCI	4.02	2	3.68	3	28.000	-3.148	0.001*
SI_{IL}-Significance indices of infrastructure and logistics barriers to CE adoption in the BCI	3.94	3	3.76	2	6.500	-1.771	0.077
SI_{EM}-Significance indices of economic and market barriers to CE adoption in the BCI	3.88	5	3.60	5	16.000	-2.410	0.016*
SI_{OG}-Significance indices of organizational barriers to CE adoption in the BCI	4.03	1	3.98	1	13.000	-1.443	0.200

Note: Test value significance: *$\rho < 0.05$.

5. Discussion of Major Findings

5.1 Organisational barriers

5.1.1 Symmetries on organizational barriers

The organizational barriers category to CE in BCI ranked 1st by both developed and developing countries with fuzzy weights of 4.03 and 3.98 respectively (see Table 5). There is no significant difference in the mean comparison between the two classes of respondents supported by ρ-value of 0.200 and a Z-value of -1.443. Therefore, organizational barriers equivalently impact developing and developed countries' adoption of CE in BCI. This is unsurprising because business-as-usual in BCI globally stifles and complicates the transition to CE since individuals, departments, and stakeholders must unlearn old processes and gain tailored competencies to stay relevant within the circular construction business model (Wuni, 2022). The BCI's overreliance on resource-intensive business models results in poor organizational preparation, resource allocation, and capacity to apply circular practices, operations, and procedures. Similarly, Bao and Lu (2020) observed that organisational barriers have the highest impact on the systemic circularity adoption in the BCI because inadequate organisational structure to CE with a lack of business model will frustrate top management adoption of CE in the BCI.

Further, within the organizational barriers category, some barriers were highly prioritized, but with no significant difference in their mean comparison. These underlying obstacles and their corresponding ranks (in bracket) include inadequate organizational effort in the development of a circular business model (ranked first by developing and developed countries, the fragmented nature of BCI and its supply chain network (9th and 14th), and lack of top management support and leadership toward circular design (15th and 12th). Since these underlying barriers also have no significant difference in their mean comparison, it connotes that the barriers hamper developing and developed countries equally on CE adoption. These findings corroborate Oluleye et al. (2022b) that most underlying barriers to CE have a similar level of effect on CE in any nation globally, thus a global policy to avert them is imperative.

5.1.2 Asymmetries on organizational barriers

Inadequate organizational resources and capabilities to support CE principle have mean values of 3.89 and 3.43 based on developing and developing countries' perspectives. Based on the mean comparison, a significant difference exit (i.e., ρ-value of 0.027 and z-value of -2.218). This indicates that the underlying barriers have prominent impact on developing countries than the developed countries. This result is noteworthy because resources and capabilities to implement CE are quite available in developed countries relative to developing countries (Mahpour, 2018). Therefore, one of the main factors that affect developing countries' adoption of CE in BCI is the unavailability of supportive resources and human capacity (Liu et al., 2021a). Hence specific policy implementation to combat this issue in developing countries is urgent.

5.2 Information technology barriers

5.2.1 Symmetries on Information technology barriers

The information technology barrier to CE in BCI was ranked 2nd and 3rd by developing and developed countries experts with a fuzzy weight of 4.02 and 3.68, respectively. There was a significant difference in the mean comparison for this barrier which is supported by a ρ-value < 0.05 and Z-value = -3.148. Thus, the information technology barriers to CE in BCI are more prevalent in developing countries. Notwithstanding the overall significant difference, certain barriers within this category showed no level of significant difference in mean comparison between developing and developed countries. These barriers and their corresponding ranks (in bracket) are lack of clearly defined CE indicators and metrics (ranked 14th and 10th), the infancy of digital tools for circularity from the beginning of life to end of life and beyond system boundary (ranked 13th and 16th), unavailability of disassembly information for demolition auditing (ranked 3rd by both groups), and unavailability of BCDW data for prediction in a CE environment (ranked 12th and 15th).

These findings are credible because digital tools and indicators for systemic circularity are global issues. Further, to optimize existing buildings as part of the decommissioning, deconstruction, and demolition process, stakeholders are in the dark about an innovative system for pre-demolition audits (Akanbi et al., 2020). Pre-demolition audits are required across the globe as part of the Building Research Establishment Environmental Assessment Method (BREEAM) construction scheme, which states that the audit should determine whether materials recovery for reuse is feasible and maximize materials recovery from demolition for subsequent up-cycling (Akanbi et al., 2020; Martinez et al., 2022). However, information and data for prediction in a CE for proper demolition auditing are not readily available globally. Hence a global policy for demolition auditing is necessary for a CE.

5.2.2 Asymmetries on information technology barriers

Based on the FSE weights, *information technology barriers* have more impact on the adoption of CE in developing countries (4.02) compared to developed countries (3.68) with a ρ-value < 0.05 confirming a significant difference between the mean comparison of the two groups. Therefore, it is important to know that lack of information technology for design for disassembly, recycling, and waste sorting has a greater impact on CE in developing countries (Mahpour, 2018). This could be because the low level of technological advancement in developing countries has a spill over effect on the advancement of CE in BCI. Therefore, since information technology has been considered a powerful tool to drive CE, effort should be put in place for its promotion in developing countries.

The underlying barriers under this group for example unavailability of effective web-based waste exchange systems and databases for the quality of secondary products ranked 5^{th} and 20^{th} by both developing countries and developed countries with mean values of 4.07 and 3.57. Moreover, there was a significant difference in the mean values comparison of the two groups which is supported by a ρ-value = 0.004 and z-value of -2.844. Based on the mean scores and the the ρ-value result, it implies that the barriers have more impact on the adoption of CE in developing countries BCI relative to the developed countries. This is not surprising due to the infancy state of developing countries in the usage of innovative databases for monitoring the quality of materials.

Lack of systemic circularity education and training for supply chain members is prioritized more by the developing countries to the slow adoption of CE in their BCI. This is supported by a mean value of 4.10 and 3.68 from developing and developed countries respectively. The difference in the mean of the two groups on comparison was confirmed by a significant ρ-value of 0.025 and a z-value of – 2.249. This indicates that the impact of a low level of education and training on CE for concerned supply chain members in the BCI is more prominent in developing countries. This finding is expected due to the low level of awareness and education for CE in developing countries as expressed in extant studies (Mahpour, 2018; Bilal et al., 2020). Therefore, policies and strategies to upskill and equip appropriate supply chain employees with the necessary CE abilities and knowledge should be specifically implemented for developing countries (Liu et al., 2021a). This is also needed in developed countries, but the need is more in developing countries.

The lack of effective CE-based knowledge management systems among stakeholders is ranked 2nd by both developing and developed countries with mean values of 4.25 and 3.85. This barrier is very critical in the two contexts toward the adoption of CE in BCI (mean >3.5). Despite the equal ranking of barriers in the two contexts, the criticality of its impact on CE in developing countries BCI is more prominent(mean=4.25). This is obvious based on the significant difference resulting in the mean comparison of the barriers between the two groups which is supported by a ρ-value of 0.014 and z-value of – 2.466. This result is not surprising because Liu et al. (2021a) earlier posited that knowledge sharing among stakeholders on CE uptake is crippled in developing countries BCI. Therefore, special policies must be put in place to trigger the creation, sharing, use, and management of knowledge related to CE development among stakeholders in developing countries.

5.3 Infrastructures and logistics barriers

5.3.1 Symmetries on infrastructures and logistics barriers

The infrastructures and logistics barriers category are ranked 3rd and 2nd by developing and developed countries with FSE weights of 3.94 and 3.76, respectively. Regarding the mean comparison, there exists no significant difference between the two independent classes of respondents which are manifested in its resultant ρ-value of 0.077 and z-value of -1.771. Consequently, infrastructural and logistics barriers are pervasive to CE in BCI in developing and developed countries. This result is not unexpected because global reverse logistics network and infrastructure of BCI's circular supply chain are inadequate (Wilson et al., 2021). Contractual arrangements and processes allowing manufacturers to return building components and goods after their lifetime for remanufacturing, recycling, and upcycling are lacking in many countries, thus limiting CE adoption in the BCI (Hartwell et al., 2021; Schlüter et al., 2021). A dearth of appropriate local supply chain partners has resulted in some countries having incomplete circular supply chains. Because of these logistics and infrastructural issues, CE is complex, time-consuming, and undesirable to stakeholders in both developing and developed nations (Kirchherr et al., 2018). Hence effective policies are needed to integrate the logistics and promote infrastructural development for CE development in BCI globally.

Further, most infrastructure and logistic barriers were highly prioritized with no significant differences in their mean comparison. These underlying barriers with their corresponding ranks by developing and developed countries experts (in bracket) include a lack of BCDW sorting and recovery infrastructure (ranked 24th and 5th) and lack of comprehensive reverse logistic networks and facilities (ranked 10th and 6th). The high ranking of the infrastructure and logistic barriers and the equal level of impact of its underlying barriers in developing and developed countries suggest an urgent need for enabling infrastructural and logistic CE strategies globally in the BCI. For instance, policies on the procurement of systemic circularity facilities and the integration of the supply chain network require improvement (Hartwell et al., 2021). This would enable a seamless reverse logistic system and an effective close loop beyond the system boundary in the BCI.

5.3.2 Asymmetries on infrastructures and logistics barriers

An underlying barrier within infrastructures and logistics barriers is lack of benchmarking process for CE adoption. This barrier was ranked 6th and 17th by developing countries and developed countries, respectively. Upon mean comparison of the underlying barriers, there exist a significant difference supported by a ρ-value of 0.034 and z-value of – 2.117. With a mean value of 4.05, the underlying barrier was prioritized higher by developing countries' experts which indicates a more need to have a threshold for CE adoption in developing countries. Developing countries should adopt a benchmarking approach for CE by measuring their progress against nations that have gotten to a significant level of systemic circularity in BCI (Mahpour, 2018). This would enable the identification of areas, systems, and processes that requires significant improvement.

5.4. Regulatory barriers

5.4.1 Symmetries on regulatory barriers

The regulatory barriers category is ranked fourth by both experts from developing and developed countries with fuzzy weights of 3.90 and 3.71 accordingly. On mean comparison, there is a considerable difference between the two groups of experts supported at a ρ-value <

0.05, and a z-value of -2.887. Certain underlying barriers within this classification show no degree of significant disparities in comparing the means of the two independent groups. This implies that the impact of such barriers in both contexts is relatively similar. These underlying barriers with their corresponding ranking(in bracket) from the perspectives of developing and developed countries include: lack of circularity guidelines for end-of-life collection and sorting of materials toward value creation(ranked 8th in developed countries and 9th in developing countries), lack of regulatory pressure and stringent penalties on dumping at a landfill(ranked 22nd and 13th), lack of supportive building codes for secondary materials(ranked 21st and 24th), lack of government promotion and commitment to design for disassembly(ranked 17th and 4th), and legislations for BCDW circularity are not binding(ranked 20th and 7th). As a result of no significant difference in the comparison of the mean, it connotes that the underlying barriers affect developing and developed countries' adoption of CE in BCI equally. This is quite interesting because the underlying barriers are quite beyond the control of experts in developing and developed countries and are more related to the government regulations towards CE in BCI. Existing policy frameworks fail to create the urgency of circularity and behavioural changes necessary to disperse CE in the building sector in the absence of regulatory pressure and stringent laws(Huang et al., 2018; Shooshtarian et al., 2022).

5.4.2 Asymmetries on regulatory barriers

Although regulatory barriers classification to CE in BCI is ranked equally by experts in developing and developed countries, the impact of the barriers is prominent in developing countries relative to developed countries based on the FSE results and the test of significance difference conducted. This implies a more pressing need for effective regulation that supports CE in developing countries' BCI. A significant difference also exists in the underlying barrier mean comparison. For instance, lack of standards on the quality of refurbished and remanufactured products is ranked 11th and 18th by developing and developed experts respectively with mean values of 3.98 and 3.58. As such there was a significant difference between the two-group supported at ρ-value of 0.002 and, a Z-value of -3.025. Although the mean scores were quite significant for the two groups, however, it is more dominant in the developing countries which implies a more pressing need for the promotion of standard and quality of refurbished construction materials in the developing countries. Liu et al. (2021a), posited that quality assurance standards should be imposed by the regulatory agencies to enable CE in developing countries.

5.5 Economic and market barriers

5.5.1 Symmetries on economic and market barriers

Economic and market barriers group is ranked 5th by both developing and developed countries' experts with FSE weights of 3.88 and 3.60 respectively. There is a significant difference on the two groups based on their mean comparison supported by a ρ-value < 0.05 and Z-value = -2.410. Thus, economic and market barriers are more prevalent in developing countries relative to developed countries. Despite the overall significant difference regarding the economic barriers, certain underlying barriers show no significant difference based on their mean comparison between the two classes of respondents. These barriers with their corresponding ranking (in bracket) based on developing and developed countries' perspectives include lack of market mechanisms for waste recovery (ranked 25th and 22nd) and lack of high-quality secondary products (ranked 19th and 8th). These results show that globally, lack of a market system for waste recovery and low quality of secondary materials has affected the development of CE in BCI (Akinade et al., 2020).

5.5.2 Asymmetries on economic and market barriers

Underlying economic and market barriers which have significant differences based on the mean comparison between developing and developed countries include lack of capital and financial resources for CE, virgin materials that are cheaper than secondary materials, and lack of markets and demand for second-hand materials. These underlying barriers were ranked higher in developing countries (mean values >3.50), implying that they are more prevalent to CE development in such context. For instance, financial means to incorporate circularity strategies into businesses, supply networks, and projects have also hindered CE in many developing countries(Huang et al., 2018; Liu et al., 2021a). In developing countries, the absence of a well-established market for circular materials entrenched nature of 'business-as-usual' has also generated limited demand for recycled materials and reused products.

5.6 Implications of the study and policy recommendation

Empirical research is often useful for continuous improvement in industrial practice through effective policy development. This study first provided the impact level of the barriers to CE in BCI in two economies and the result could serve as an allocative function in combating the barriers investigated. Second, this study established that although CE is a global initiative, there are challenges facing its implementation which could be different or similar in developing or developed economies. Therefore, this research revealed that there are specific and generic barriers to CE implementation in BCI. The specific barriers influence CE implementation differently in developed and developing countries and they include legislative, information technology, and economic and market barriers. Furthermore, the generic barriers impact CE adoption equally in any economy and they include infrastructure and logistics, and organizational barriers. This understanding will practically guide the development of generic policy and specific policies by global and regional organizations toward a wider CE adoption in the BCI.

It is recommended that policy development towards combating the specific barriers should be the focus of regional/countries/economies-based organisations advocating for CE adoption such as the African Circular Economy Alliance (ACEA), African Circular Economy Network (ACEN), and the government CE programmes of each country, for example, the Circular Economy Programme of the Netherlands, and the Circular Economy Action Plan of the European Council.

At a global level, this study revealed that the generic barriers that require the most attention are organizational-related. This barrier also shows the same level of impact in developing and developed countries. Therefore, a fundamental requirement of global organisations is to develop and ensure effective policies such as mandating BCI stakeholders' commitment to the development and modification of circular business models globally to create, deliver, and capture value in CE without wasting materials and toward zero waste. Besides, promulgated government policies that would enhance BCI and supply chain members' support circular design must be put in place globally. Further, the capacities of stakeholders within the organisations should be improved in circular construction projects to enable an accelerated global CE execution in BCI.

In controlling infrastructure and logistic barriers at a wider level, the key areas that should be considered by global organisations include the supply chain reverse logistics, waste sorting, and infrastructural facilities. Policies toward returning waste or faulty products to the manufacturer via a reverse supply chain system for re-manufacturing (either through refurbishment, or recycling) should be properly implemented. Since reverse logistics is an efficient way and shortest way to complete a material's lifecycle, hence, effective policies that will assist both developing and developed countries are necessary. To determine the next use cycle for each returned product such as reuse, recovering components through parts harvesting for remanufacturing, or recycling, a firm must assess several criteria, including the product's condition and the current market environment which requires effective policies. In the network design of reverse logistics, such as infrastructural configuration, processing facilities for sorting, and location of the materials collection point can be properly enhanced via a benchmarking process and policies.

Regarding the specific barriers, each region or country should focus on developing a strategic approach towards developing effective information technology policies for systemic circularity adoption. However, due to the ranking of the barriers (2nd and 3rd by developing and developed countries), they are deemed critical to the development of CE. Thus, policies for information technology that will enhance databases for prediction in a CE, demolition auditing, recycling, waste sorting, knowledge management, and training of expertise should be implemented. Although this barrier has varying levels of impact in developing and developed countries, it is important to develop specific policies for each context based on individual peculiarities to attain a desirable systemic circularity.

Further, specific policy development is essential for effective regulatory environment for a CE adoption in the BCI of \ developing and developed countries considering the relative impact of regulatory barriers. Ineffective circularity guidelines, lack of regulatory pressure for CE, lack of standards for secondary materials, and lack of government support for design for disassembly have delayed the development of CE in BCI. Therefore, regulatory environment that would enforce CE via government intervention and mandating design for circularity and benchmarking standards for the quality of second-hand materials are important. Further, environmental law must be implemented that would mitigate BCDW deposit at landfill and certify the reuse and recycling of waste. However, the implementation of these policies should consider the uniqueness of developing and developed countries due to the varied level of impact that regulatory barriers have on CE in BCI.

Effective specific policies should be executed for developing and developed economies differently to alleviate most of the economic and market problems related to CE in BCI. For instance, to control the increased prices of secondary materials, the cost of eco-friendly materials should be reduced with the prices of virgin materials. Such policies will increase market demand for second-hand materials in construction. Additionally, markets for second-hand materials should be established while promoting the suppliers of secondary construction materials.

6. Conclusions

To understand specific and generic barriers militating CE advancement in BCI, this study evaluated the symmetries and asymmetries on the barriers based on CE experts' perspectives from developing and developed economies. Following a multistage methodological approach, it was revealed that organizational, information technology, and infrastructure and logistics barriers categories, are the most critical to CE adoption in the BCI of developing and developed countries but with varying levels of impact. Further, the symmetries and asymmetries on the barriers to CE adoption in BCI using the Mann-Whitney *U* test demonstrate a considerable discrepancy in the viewpoints of experts from developing and developed economies on regulatory, information technology, and economic and market barriers. As a result, they are labeled as specific barriers since they exhibit a different influence on CE adoption in BCI between the two economies. However, infrastructure and logistics, and organizational barriers are categorized as generic barriers to CE implementation in BCI since they influence CE adoption equally in the two economies investigated.

The first contribution of this research is that it provides a better understanding of barriers that requires generic policies and those that require specific policies which will guide both global organizations and regional organizations in circularity policy development. Second, the significance indices of the categorization of the barriers using FSE can serve as an allocative function for policymakers in allocating resources to tackle the barriers impeding CE adoption in BCI towards zero waste in developing and developed economies.

Moreover, the result of this study must be examined against the following limitations. First, the study constitutes a global one but the sample size, although adequate, may be considered small, hence future studies could use much larger sample sizes from both developing and developed countries. Second, the study adopted FSE analysis for determining the significant indices of the barriers categories, but the method has its limitations. Future research may address this methodological limitation by using other methods such as structural equation modelling (SEM), artificial neural networks (ANN), or fuzzy analytical hierarchy process (FAHP). Third, expertise in CE in the BCI is still augmenting, therefore, this study may have to be repeated in the future to capture more experience-based opinions for evaluation. The study identified specific and generic barriers related to CE adoption in developing and developed economies which could be very informative in conducting further rigorous studies in specific countries to consolidate existing findings.

Appendix 1: Fuzzy synthetic evaluation steps

Stage 1: Fuzzy synthetic evaluation index development

The adopted index system which forms the input parameter is presented as:

RE = {*RE1, RE2, RE3, RE4, RE5, RE6*}

TE = {*TE1, TE2, TE3, TE4, TE5, TE6, TE7*}

IL = {*IL1, IL2, IL3*}

EM = {*EM1, EM2, EM3, EM4, EM5*}

OG = {*OG1, OG2, OG3, OG4*}.

Stage 2: Computing the weightings of the barriers and the classification of the barriers to CE adoption in BCI

Using a developing country perspective, for instance, the *information technology barrier (TE),* the weighting of the underlying barrier "*the infancy of digital tools for circularity from the beginning of life to the end of life and beyond system boundary"* is computed as:

$$Wi = \frac{3.97}{3.97+3.97+4.11+4.07+4.10+3.97+4.25} = 0.140$$

Further, the classification of the barrier's weightings is computed by dividing their mean values (which is the summation of their respective underlying barrier's mean) by the cumulative mean values of all the classification of barriers). For instance, *information technology barrier (TE)* weighting for developing countries is computed as illustrated below:

$$Wi \text{ (classification of barriers-TE)} = \frac{28.44}{23.35+28.44+11.80+19.26+16.18} = 0.287$$

A similar approach was adopted in computing the weightings of other underlying and classifications of barriers (See Table 4). This forms the basis computing of the membership function.

Stage 3. Computation of the membership functions (MF) of the underlying barriers to CE in BCI

Using '*infancy of data-driven digital tools for circularity"* from the developing economy perspective, *for* example, 2% ranked it as "not significant", 3% ranked it as "less significant",18% were "uncertain", 51% of the respondents ranked it as "significant" while 26% ranked it as "very significant". Given that B_{1TE2} is the percentage of the responses per each rating on the barrier, then the MF of (*infancy of data-driven digital tools for circularity) could be illustrated as:*

$$MF_{TE2} = \frac{0.02}{Ч_1} + \frac{0.03}{Ч_2} + \frac{0.18}{Ч_3} + \frac{0.51}{Ч_4} + \frac{0.26}{Ч_5}$$

Since the "+" represents a notation and not an addition, in the FSE process, thus the MF can be expressed as: MF_{TE2} = (0.02, 0.03, 0.18, 0.51, 0.26)

Stage 4: Computation of the membership function (MF) of the classification of the barriers to CE in BCI

Using the *information technology barriers category (TE) based on developing country perspectives, for example*, its fuzzy matrix (M_i) can be illustrated as.

$$M_i = \begin{pmatrix} MF_{1TE_1} \\ MF_{1TE_2} \\ MF_{1TE_3} \\ MF_{1TE_4} \\ MF_{1TE_5} \\ MF_{1TE_6} \\ MF_{1TE_7} \end{pmatrix} = \begin{pmatrix} B_{1TE1} & B_{2TE1} & B_{3TE1} & B_{4TE1} & B_{5TE1} \\ B_{1TE2} & B_{2TE2} & B_{3TE2} & B_{4TE2} & B_{5TE2} \\ B_{1TE3} & B_{2TE3} & B_{3TE3} & B_{4TE3} & B_{5TE3} \\ B_{1TE4} & B_{2TE4} & B_{3TE4} & B_{4TE4} & B_{5TE4} \\ B_{1TE5} & B_{2TE5} & B_{3TE5} & B_{4TE5} & B_{5TE5} \\ B_{1TE6} & B_{2TE6} & B_{3TE6} & B_{4TE6} & B_{5TE6} \\ B_{1TE7} & B_{2TE7} & B_{3TE7} & B_{4TE7} & B_{5TE7} \end{pmatrix}$$

Having obtained the fuzzy matrix(M_i), the MF (D_i) was computed as illustrated:

$D_i = W_i * M_i = (d_{i1}, d_{i2}, d_{i3}, \ldots, d_{in})$

W_i = (w1, w2, w3, …, wn), hence,

$$D_i = (w1, w2, w3, \ldots, wn) * \begin{pmatrix} B_{1TE1} & B_{2TE1} & B_{3TE1} & B_{4TE1} & B_{5TE1} \\ B_{1TE2} & B_{2TE2} & B_{3TE2} & B_{4TE2} & B_{5TE2} \\ B_{1TE3} & B_{2TE3} & B_{3TE3} & B_{4TE3} & B_{5TE3} \\ B_{1TE4} & B_{2TE4} & B_{3TE4} & B_{4TE4} & B_{5TE4} \\ B_{1TE5} & B_{2TE5} & B_{3TE5} & B_{4TE5} & B_{5TE5} \\ B_{1TE6} & B_{2TE6} & B_{3TE6} & B_{4TE6} & B_{5TE6} \\ B_{1TE7} & B_{2TE7} & B_{3TE7} & B_{4TE7} & B_{5TE7} \end{pmatrix}$$

d_{in} denotes the degree of membership of the grade's alternatives for the underlying barriers.

Following this matrix system, the MFs of all other barriers classification were computed (a detailed result is presented in Table 4).

Stage 5: Determining the criticalities/significance indices of the classification of the barriers

The significance indices of the various classification of barriers to CE in BCI for developing countries is presented as:

SI_{RE} = (0.02, 0.06, 0.20, 0.44, 0.28) × (1, 2, 3, 4, 5) =3.90

SI_{TE} = (0.02, 0.03, 0.15, 0.46, 0.33) × (1, 2, 3, 4, 5) = 4.02

SI_{IL} = (0.03, 0.04, 0.18, 0.46, 0.29) × (1, 2, 3, 4, 5) = 3.94

SI_{EM} = (0.03, 0.07, 0.23, 0.43, 0.26) × (1, 2, 3, 4, 5) = 3.88

SI_{OG} = (0.02, 0.03, 0.17, 0.41, 0.36) × (1, 2, 3, 4, 5) = 4.03

Also, the significance indices of the various classification of barriers to CE in BCI for developed countries is presented as:

SI_{RE} = (0.06, 0.08, 0.27, 0.32, 0.28) × (1, 2, 3, 4, 5) = 3.71

SI_{TE} = (0.05, 0.09, 0.20, 0.40, 0.25) × (1, 2, 3, 4, 5) = 3.68

SI_{IL} = (0.07, 0.05, 0.23, 0.40, 0.26) × (1, 2, 3, 4, 5) =3.76

SI_{EM}= (0.07, 0.09, 0.25, 0.36, 0.23) × (1, 2, 3, 4, 5) = 3.60

SI_{OG} = (0.07, 0.08, 0.23, 0.34, 0.34) × (1, 2, 3, 4, 5) = 3.98

References

Adabre, M. A., Chan, A. P. C., Edwards, D. J., & Mensah, S. (2022a). Evaluation of symmetries and asymmetries on barriers to sustainable housing in developing countries. *Journal of Building Engineering*, *50*, 104174. https://doi.org/https://doi.org/10.1016/j.jobe.2022.104174

Adabre, M. A., Chan, A. P. C., Edwards, D. J., & Osei-Kyei, R. (2022b). To build or not to build, that is the uncertainty: Fuzzy synthetic evaluation of risks for sustainable housing in developing economies. *Cities*, *125*, 103644. https://doi.org/https://doi.org/10.1016/j.cities.2022.103644

Adams, K. T., Osmani, M., Thorpe, T., & Thornback, J. (2017). Circular economy in construction: current awareness, challenges and enablers. *Proceedings of the Institution of Civil Engineers - Waste and Resource Management*, *170*(1), 15-24. https://doi.org/10.1680/jwarm.16.00011

Ajayi, S. O., Oyedele, L. O., Bilal, M., Akinade, O. O., Alaka, H. A., Owolabi, H. A., & Kadiri, K. O. (2015). Waste effectiveness of the construction industry: Understanding the impediments and requisites for improvements. *Resources, Conservation and Recycling*, *102*, 101-112.

Akanbi, L. A., Oyedele, A. O., Oyedele, L. O., & Salami, R. O. (2020). Deep learning model for Demolition Waste Prediction in a circular economy [Article]. *Journal of Cleaner Production*, *274*, Article 122843. https://doi.org/10.1016/j.jclepro.2020.122843

Akinade, O., Oyedele, L., Oyedele, A., Davila Delgado, J. M., Bilal, M., Akanbi, L., Ajayi, A., & Owolabi, H. (2020). Design for deconstruction using a circular economy approach: barriers and strategies for improvement [Article]. *Production Planning and Control*, *31*(10), 829-840. https://doi.org/10.1080/09537287.2019.1695006

Almohassen, A. S., Alkhaldi, M. S., & Shaawat, M. E. (2022). The Effects of COVID-19 on Safety Practices in Construction Projects. *Ain Shams Engineering Journal*, 101834.

Ayçin, E., & Kayapinar Kaya, S. (2021). Towards the circular economy: Analysis of barriers to implementation of Turkey's zero waste management using the fuzzy DEMATEL method [Article]. *Waste Management and Research*, *39*(8), 1078-1089. https://doi.org/10.1177/0734242X20988781

Bao, & Lu. (2020). Developing efficient circularity for construction and demolition waste management in fast emerging economies: Lessons learned from Shenzhen, China [Article]. *Science of the total environment*, *724*, Article 138264. https://doi.org/10.1016/j.scitotenv.2020.138264

Bilal, M., Khan, K. I. A., Thaheem, M. J., & Nasir, A. R. (2020). Current state and barriers to the circular economy in the building sector: Towards a mitigation framework. *Journal of Cleaner Production*, *276*, 123250. https://doi.org/https://doi.org/10.1016/j.jclepro.2020.123250

Chen, X., & Lu, W. (2017). Identifying factors influencing demolition waste generation in Hong Kong. *Journal of Cleaner Production*, *141*, 799-811.

Circle Economy, C. (2022). The Circularity Gap Report 2022 (pp. 1-64, Rep.). Amsterdam: Circle Economy. *Ruparo, Amsterdam*.

Condotta, M., & Zatta, E. (2021). Reuse of building elements in the architectural practice and the European regulatory context: Inconsistencies and possible improvements [Article]. *Journal of Cleaner Production*, *318*, Article 128413. https://doi.org/10.1016/j.jclepro.2021.128413

Cruz Rios, Grau, D., & Bilec, M. (2021). Barriers and Enablers to Circular Building Design in the US: An Empirical Study. *Journal of Construction Engineering and Management*, *147*(10), 04021117.

Ding, Z., Liu, R., Wang, Y., Tam, V. W., & Ma, M. (2021). An agent-based model approach for urban demolition waste quantification and a management framework for stakeholders [Article]. *Journal of Cleaner Production*, *285*, Article 124897. https://doi.org/10.1016/j.jclepro.2020.124897

Dunant, C. F., Drewniok, M. P., Sansom, M., Corbey, S., Allwood, J. M., & Cullen, J. M. (2017). Real and perceived barriers to steel reuse across the UK construction value chain. *Resources, Conservation and Recycling*, *126*, 118-131.

Giorgi, S., Lavagna, M., Wang, K., Osmani, M., Liu, G., & Campioli, A. (2022). Drivers and barriers towards circular economy in the building sector: Stakeholder interviews and analysis of five European countries policies and practices. *Journal of Cleaner Production*, *336*, 130395. https://doi.org/https://doi.org/10.1016/j.jclepro.2022.130395

Guerra, F. (2021). Circular economy in the construction industry: An overview of United States stakeholders' awareness, major challenges, and enablers. *Resources, Conservation and Recycling*, *170*, 105617. https://doi.org/https://doi.org/10.1016/j.resconrec.2021.105617

Hartwell, Macmillan, S., & Overend, M. (2021). Circular economy of façades: Real-world challenges and opportunities [Article]. *Resources, Conservation and Recycling*, *175*, Article 105827. https://doi.org/10.1016/j.resconrec.2021.105827

Heurkens, E., & Dąbrowski, M. (2020). Circling the square: Governance of the circular economy transition in the Amsterdam Metropolitan Area. *European Spatial Research and Policy*, *27*(2), 11-31.

Hossain, M. U., Ng, S. T., Antwi-Afari, P., & Amor, B. (2020). Circular economy and the construction industry: Existing trends, challenges and prospective framework for sustainable construction [Review]. *Renewable and Sustainable Energy Reviews*, *130*, Article 109948. https://doi.org/10.1016/j.rser.2020.109948

Huang, B., Wang, X., Kua, H., Geng, Y., Bleischwitz, R., & Ren, J. (2018). Construction and demolition waste management in China through the 3R principle [Article]. *Resources, Conservation and Recycling*, *129*, 36-44. https://doi.org/10.1016/j.resconrec.2017.09.029

Jin, R., Li, B., Zhou, T., Wanatowski, D., & Piroozfar, P. (2017). An empirical study of perceptions towards construction and demolition waste recycling and reuse in China [Article]. *Resources, Conservation and Recycling*, *126*, 86-98. https://doi.org/10.1016/j.resconrec.2017.07.034

Joensuu, T., Edelman, H., & Saari, A. (2020). Circular economy practices in the built environment. *Journal of Cleaner Production*, *276*. https://doi.org/10.1016/j.jclepro.2020.124215

Kanters, J. (2020). Circular Building Design: An Analysis of Barriers and Drivers for a Circular Building Sector. *Buildings*, *10*(4). https://doi.org/10.3390/buildings10040077

Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., & Hekkert, M. (2018). Barriers to the Circular Economy: Evidence From the European Union (EU). *Ecological Economics*, *150*, 264-272. https://doi.org/https://doi.org/10.1016/j.ecolecon.2018.04.028

Liu, J., Wu, P., Jiang, Y., & Wang, X. (2021a). Explore potential barriers of applying circular economy in construction and demolition waste recycling [Article]. *Journal of Cleaner Production*, *326*, Article 129400. https://doi.org/10.1016/j.jclepro.2021.129400

MacFarland, T. W., & Yates, J. M. (2016). Mann–whitney u test. In *Introduction to nonparametric statistics for the biological sciences using R* (pp. 103-132). Springer.

Mahpour, A. (2018). Prioritizing barriers to adopt circular economy in construction and demolition waste management [Article]. *Resources, Conservation and Recycling*, *134*, 216-227. https://doi.org/10.1016/j.resconrec.2018.01.026

Martinez, P., Mohsen, O., Al-Hussein, M., & Ahmad, R. (2022). Vision-based automated waste audits: a use case from the window manufacturing industry. *The International Journal of Advanced Manufacturing Technology*, *119*(11), 7735-7749. https://doi.org/https://doi.org/10.1007/s00170-022-08730-2

Oluleye, B. I., Chan, D. W. M., & Olawumi, T. O. (2022b). Barriers to circular economy adoption and concomitant implementation strategies in building construction and demolition waste management: A PRISMA and interpretive structural modeling approach. *Habitat International*, *126*, 102615. https://doi.org/https://doi.org/10.1016/j.habitatint.2022.102615

Oluleye, B. I., Chan, D. W. M., Saka, A. B., & Olawumi, T. O. (2022a). Circular economy research on building construction and demolition waste: A global review of current trends and future

research directions. *Journal of Cleaner Production*, 131927. https://doi.org/https://doi.org/10.1016/j.jclepro.2022.131927
Ormazabal, M., Prieto-Sandoval, V., Puga-Leal, R., & Jaca, C. (2018). Circular economy in Spanish SMEs: challenges and opportunities. *Journal of Cleaner Production*, *185*, 157-167.
Pham, H., Pham, T., & Dang, C. N. (2021). Assessing the importance of transformational leadership competencies and supply chain learning to green innovation: construction practitioners' perspectives. *Construction Innovation*.
Ramos, M., & Martinho, G. (2021). Influence of construction company size on the determining factors for construction and demolition waste management [Article]. *Waste Management*, *136*, 295-302. https://doi.org/10.1016/j.wasman.2021.10.032
Ranta, V., Aarikka-Stenroos, L., Ritala, P., & Mäkinen, S. J. (2018). Exploring institutional drivers and barriers of the circular economy: A cross-regional comparison of China, the US, and Europe. *Resources, Conservation and Recycling*, *135*, 70-82. https://doi.org/https://doi.org/10.1016/j.resconrec.2017.08.017
Ratnasabapathy, S., Alashwal, A., & Perera, S. (2021a). Exploring the barriers for implementing waste trading practices in the construction industry in Australia [Article]. *Built Environment Project and Asset Management*, *11*(4), 559-576. https://doi.org/10.1108/BEPAM-04-2020-0077
Ratnasabapathy, S., Alashwal, A., & Perera, S. (2021b). Exploring the barriers for implementing waste trading practices in the construction industry in Australia [Article]. *Built Environment Project and Asset Management*. https://doi.org/10.1108/BEPAM-04-2020-0077
Rios, C., Grau, D., & Bilec, M. (2021). Barriers and Enablers to Circular Building Design in the US: An Empirical Study [Article]. *Journal of Construction Engineering and Management*, *147*(10), Article 04021117. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002109
Saka, A. B., Chan, D. W. M., & Wuni, I. Y. (2022). Knowledge-based decision support for BIM adoption by small and medium-sized enterprises in developing economies. *Automation in Construction*, *141*, 104407.
Schlüter, M., Lickert, H., Schweitzer, K., Bilge, P., Briese, C., Dietrich, F., & Krüger, J. (2021). AI-enhanced identification, inspection and sorting for reverse logistics in remanufacturing. *Procedia CIRP*, *98*, 300-305.
Shooshtarian, S., Hosseini, M. R., Kocaturk, T., Arnel, T., & T. Garofano, N. (2022). Circular economy in the Australian AEC industry: investigation of barriers and enablers. *Building Research & Information*, 1-13. https://doi.org/10.1080/09613218.2022.2099788
Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. *International journal of medical education*, *2*, 53.
Udawatta, N., Zuo, J., Chiveralls, K., & Zillante, G. (2015). Improving waste management in construction projects: An Australian study. *Resources, Conservation and Recycling*, *101*, 73-83. https://doi.org/https://doi.org/10.1016/j.resconrec.2015.05.003
Upadhyay, A., Laing, T., Kumar, V., & Dora, M. (2021b). Exploring barriers and drivers to the implementation of circular economy practices in the mining industry. *Resources Policy*, *72*, 102037. https://doi.org/https://doi.org/10.1016/j.resourpol.2021.102037
Wilson, M., Paschen, J., & Pitt, L. (2021). The circular economy meets artificial intelligence (AI): understanding the opportunities of AI for reverse logistics. *Management of Environmental Quality: An International Journal*. https://doi.org/https://doi.org/10.1108/MEQ-10-2020-0222
Wuni, I. Y. (2022). Mapping the barriers to circular economy adoption in the construction industry: A systematic review, Pareto analysis, and mitigation strategy map. *Building and Environment*, *223*, 109453. https://doi.org/https://doi.org/10.1016/j.buildenv.2022.109453
Xu, Y., Yeung, J. F. Y., Chan, A. P. C., Chan, D. W. M., Wang, S. Q., & Ke, Y. (2010). Developing a risk assessment model for PPP projects in China — A fuzzy synthetic evaluation approach. *Automation in Construction*, *19*(7), 929-943. https://doi.org/https://doi.org/10.1016/j.autcon.2010.06.006

Yu, Y., Junjan, V., Yazan, D. M., & Iacob, M.-E. (2022). A systematic literature review on Circular Economy implementation in the construction industry: a policy-making perspective. *Resources, Conservation and Recycling*, *183*, 106359. https://doi.org/https://doi.org/10.1016/j.resconrec.2022.106359

Assessment of symmetries and asymmetries on barriers to circular economy adoption in the construction industry: A survey of international experts

Study highlights

1. An international survey on barriers to CE implementation in the BCI was conducted.
2. Symmetries exist on three barriers groups and were labeled general barriers.
3. Asymmetries exits on other two barriers group and were tagged specific barriers.
4. The study will guide general and specific policies execution for CE adoption in the BCI.

Declaration of interest

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