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Selection of Circular Proposals in Building Projects: An MCDM Model for Lifecycle Circularity Assessments Using AHP

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Abstract: The circular economy (CE) in construction literature engages with individual CE concepts, mostly at the 'macro'/'meso' levels, and lacks holistic frameworks of indicators for circularity assessments (CAs) to inform decision-making at the 'micro' (project) level. This article presents a model using the Analytic Hierarchy Process (AHP) for circular proposal selection in building projects based on a previously validated conceptual framework. The model involves twelve circularity indicators (CIs) classed under five themes relevant to building lifecycle stages. A questionnaire survey was used to establish the final weight vector of CIs. Participants acknowledged the immediate and prolonged effects of design on circularity and viewed waste as 'design flaws' but focused on aspirational design indicators relevant to achieving future circularity and missed opportunities for embedding circular materials in design. Moreover, UK participants showed distinctive behaviours towards CAs (proactive/reactive) based on work experience. 'UK-Experts' focused on 'front-end' design indicators, while 'UK-Non-experts' focused on 'back-end' waste management indicators. The findings indicate a partial transition to CE better described as a 'recycle/reuse economy'. CAs and multiple-criteria decision-making (MCDM) techniques facilitate automated decision-making, which provides a new pathway to digital transformation within built environment. Future research will develop a decision-making tool and apply the proposed model in real-life projects.

Keywords: construction circular economy; lifecycle circularity assessments; circularity indicators; built environment; multiple-criteria decision-making; analytic hierarchy process

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1. Introduction

1.1. Background

The environmental impact of building projects and the accumulation of high amounts of construction and demolition wastes (C&DW) is a cause of concern [1,2]. Construction and built environment activities consume 50% of all materials extracted and are responsible for 33% of the total waste generated; thus, they play a key role in the transition to a circular economy in Europe [3]. Recent studies have attempted to embed circularity assessments (CAs) in decision-making practices in the built environment, see Section 1.2. Nevertheless, building appraisal practices remain largely focused on the assessment of the financial and technical feasibility of the project [4,5]. Hence, project appraisal methods need updating to incorporate new concepts and respond to changing environments [5].

Decision-makers should evaluate project alternatives and make selections using an agreed set of criteria to not only encompass economic concerns, but also environmental and social concerns [6]. Designers operate within the constraints of bounded rationality, and the circular economy (CE) concept provides discursive resources that can be mobilised to frame design choices and challenge more traditional narratives of economic efficiency [7]. For example, Cambier et al. [8] pinpointed the urgent need for producing decision-making tools to inform designers' selections and embed circularity in building design. Conversely, current literature, e.g., Geraedts et al. [9], still assesses the circularity of project alternatives from the economic perspective using lifecycle cost frameworks to improve the financial performance of the building through the reuse/recycle of its components at the end-of-life stage to maximise the residual value of building materials. Moreover, the environmental criteria considered in building appraisal continue to be dominated by energy considerations to fine-tune the building's energy performance during operation [10], with a focus on assessing sustainability of the 'in use' stage rather than the circularity of the building, as a product, throughout its lifecycle. Hence, CAs remain a gap in the current building appraisal literature.

1.2. Circularity Assessment in Building Projects

The CE paradigm has provided construction with powerful principles and challenging concepts to promote the transition to sustainable construction, reduce its environmental impact, and increase the resource-efficiency of operations [2,11–13], with a focus on the 'solid material use' level [14]. Despite the extended discussions on the CE at the macro (national, regional) and meso (industrial symbiosis, eco-industrial parks) levels, the circularity of organisations/products/projects at the micro level has so far received little attention in the literature [15]. Moreover, the Ellen MacArthur Foundation [16] noted the lack of a valid framework and tools for CAs, with suspicions of driving "circularity for circularity's sake" [17]. Hence, there have been calls to use sectoral circularity indicators to track the progress toward the CE in individual sectors [17,18], and to evaluate the circularity of products/projects at the micro level [17,19,20] by measuring the embedment of CE principles throughout the entire product/project lifecycle [19,21–24].

In terms of relevance to CA frameworks in building projects, two industry reports provided early attempts to establish links with CE principles and thereby promote the CE to the built environment, namely the CE100 Network's ReSolve framework by the Ellen MacArthur Foundation [25] and the 'Circular Economy Guidance for Construction Clients' report by the UK Green Building Council [26]. However, these reports were high-level and did not provide a holistic framework of indicators whereby circularity throughout the building project lifecycle can be assessed [23]. Moreover, the CE literature has general shortcomings (see Table 1) that have combined to decelerate the introduction of a widely accepted framework of circularity indicators to inform decision-making in the built environment. In the absence of such indicators, it will be difficult to provide sufficient evidence (commercial or moral) to support decision-makers to implement a behaviour change and value more circular practices over linear ones.

Table 1. Six criticisms of the CE literature from the circularity assessments (CAs) perspectives.

Criticism	Description
Criticism 1	CE literature and related practices tend to have narrower objectives and engage with conceptual discussions about individual CE concepts [27–29].
Criticism 2	The construction CE literature lacks a holistic framework for systematic assessment of 'circularity' throughout different project/product lifecycles [30,31].
Criticism 3	This situation does not allow for the granular comparison of circularity within different options being considered for a project brief and, therefore, does not facilitate decision-making, i.e., option selection [21,25,26].
Criticism 4	Existing frameworks tend to emphasise material flows rather than material reduction [32–34].
Criticism 5	Research mostly considers functionality at the meso level for organisations having little direct influence/engagement (through an explicit business case) with practice (micro level); minimal engagement with the operational management of circularity [35–37].
Criticism 6	There is a need for a more stratified approach to support multiple-criteria DM [38,39].

Despite being an emerging field of research, several recent studies concerning metrics and indicators used for assessing building circularity have been identified. For example, Zhang et al. [40] proposed a model for measuring building circularity that included five indicators; three related to material flows ('material source in input', 'material source in output', 'efficiency of recycling'), in addition to an extra two related to building performance ('functional units achieved', 'lifetime'). Moreover, Tokazhanov et al. [24] reviewed the literature and identified 31 critical actions to support circularity in building projects in emerging economy countries and assessed the legislative readiness of local laws to support those actions; however, their list included the CE as well as sustainability-related actions. Similarly, and blurred by sustainability assessments, earlier work by Kubbinga et al. [41] proposed indicators for possible inclusion in BREEAM to cover circularity assessments in buildings. De Oliveira et al. [42] conducted a systematic literature review and identified 58 circularity indicators at the nano (product) and micro (company) levels to assist decision-making; however, their list combined both circularity and sustainability indicators and they failed to adopt a structured approach to organising their indicators to facilitate comparisons and support decision-making in real-life scenarios.

Other studies adopted a very narrow approach to building circularity assessments, focusing on individual CE concepts or specific building lifecycle stages. For example, Antonini et al. [43] focused on indicators of reversibility and durability, Hamida et al. [44] analysed the literature and identified ten common building circularity determinants related to a building's adaptability, Sagan and Sobotka [45] developed a tool to identify factors influencing waste minimisation indicators throughout the lifecycle of building structures; Cottafava and Ritzen [46] used a multiple case study approach to explore the impact of design for disassembly (DfD) on circularity of materials in building projects; while Zimmermann et al. [47] proposed an LCA framework to evaluate circularity in existing buildings, and Gravagnuolo et al. [48] evaluated the environmental impacts of historic building conservations from a CE perspective.

Finally, Khadim et al. [49] completed a review of 51 publications and 35 existing CE-related tools, and yet, concluded that the extant literature lacks comprehensive CE assessment tools, and has failed to provide a universally recognised framework for circularity assessments in building projects. That latter point is, perhaps inevitably, a result of increased research activity in a previously under-researched area produces a range of possible "solutions". Thus, there is arguably evidence that the literature has adopted a narrow, rather than a holistic, approach to circularity assessments primarily constituted by quantitative studies focused on flows of materials and waste management strategies, and it has overlooked qualitative indicators relevant to CE enabling factors. Moreover, the literature neither attempted to establish clear conceptual contours between sustainability and circularity assessments nor offered integrated and validated tools to embed circularity assessments in construction decision-making practices.

1.3. A Conceptual Model for CAs of Building Proposals

Early decisions in the pre-design stage concerning the selection between alternative building proposals (i.e., design options considered for the realisation of the building or its individual systems) that can be evidenced as based on appropriate criteria engender confidence that the most circular proposal has been selected. The 'Project Life-cycle Assessment Circularity Indicators and Themes (PLACIT)' framework proposed by Abadi et al. [23] is proposed as a circular building proposal selection in this research. PLACIT adopts a 'project life-cycle assessment (PLA)' approach for CAs in construction projects. It provides a holistic framework including five main circularity themes (CTs); four are relevant to the main stages in a building lifecycle, while the fifth acknowledges the role of project management in embracing principles of CE. Themes include: (a) 'design for circularity' to link to the 'design stage', (b) 'reduced construction impact' to link to the 'construction stage', (c) 'sustainable utilisation and maintenance' to link to the 'operation stage', (d) 'C&D waste management' to link to 'closing material loops' during 'construction' and 'decommissioning' stages and (e) 'CE management' for managerial indicators that cannot be included in other themes. Subsequently, CE principles and associated concepts and requirements were identified by reviewing the core construction CE literature, which were in turn grouped into 12 circularity indicators (CIs) embodying high-level requirements of CE relevant to the five themes (Table 2).

Table 2. PLACIT framework for circularity assessments (CAs) based on Abadi et al. Reprint with permission [23]; 2022, ICE Publishing.

Circularity Themes (CTs)	Circularity Indicators (CIs)
Design for Circularity in Construction (Design Stage)	■ CI-1: Design Solutions to Maximise Future Circularity: (e.g., Design for Disassembly, Longevity, and Modularisation . . . etc.) ■ CI-2: Use of Low-impact Innovative Materials ■ CI-3: Embed Recycled Materials in Design
Reduced Construction Impact (Construction Stage)	■ CI-4: Reduced Material Inputs: (e.g., Efficient Construction Processes, Sharing Equipment . . . etc.) ■ CI-5: Innovative Construction Methods: (e.g., Off-site Construction and Three-dimensional Printing . . . etc.)
Sustainable Utilisation and Maintenance (Operation Stage)	■ CI-6: Durability of Building, Asset or Project: (e.g., Efficient Use, Repair, Maintenance and Repurpose) ■ CI-7: Reduced Environmental Impact of Operation: (e.g., Carbon Emissions, Energy Consumption and Domestic Waste Mgmt.)
C&D Waste Management (Closing Material Loops)	■ CI-8: Construction Waste Management: (e.g., Waste Minimisation, Material & Equipment Recovery for Onward Reuse) ■ CI-9: Demolition Waste Management: (e.g., Integrating the 3R Framework and Waste Management Hierarchy)
CE Management (Business Models, Education and Data Mgmt.)	■ CI-10: New Business Models and Strategies ■ CI-11: Planning, Collaboration, and CE Data Management ■ CI-12: Education, Training, and Stakeholder CE Awareness

The CE in construction literature has lacked a holistic framework for assessing the circularity of construction activities at the micro, i.e., project, level. The value of PLACIT for supporting MCDM using AHP in this study is attributed to two main features that address shortcomings of the current CA literature discussed in Section 1.2. Firstly, it provides a holistic framework of indicators that track the adoption of CE principles/concepts throughout the whole lifespan of the "product", i.e., the building, rather than partial assessments based on evaluating the flow of individual building materials or the application of individual CE concepts in building projects. Secondly, PLACIT features a hierarchical (stratified) structure with twelve indicators classed under five themes relevant to the main stages in a building lifecycle. The stratified structure allows granular assessments of alternatives and facilitates the use of structured multiple-criteria decision-making (MCDM) methods to inform circular selections. In this research, alternative building proposals will be scored for their engagement with CIs included in PLACIT framework, and rankings and selection will be based on their total circularity scores.

1.4. MCDM as a New Pathway to Digital Transformation within Circular Built Environment

Sawhney et al. [50] believe a digital ecosystem cannot govern itself and that current 'construction 4.0' technologies lack the cognition necessary to automate the decision-making process and facilitate innovation diffusion at the project level. Hierarchical decision-making and optimisation techniques provide the link between circular supply chains and Industry 4.0 technologies [51], and have the potential to support digital deconstruction platforms to assess existing building components, inform strategies for material recovery planning, and improve waste and inventory management [52]. Rogers and Duffy [6] suggest three multiple-criteria decision-making (MCDM) methods widely used to support the selection of optimum alternatives in engineering projects: simple additive weighting (SAW), analytic hierarchy process (AHP) and concordance analysis.

AHP has multiple advantages over other MCDM methods, and hence was used in this research for a "circular" building proposal selection based on PLACIT. First, AHP as a structured multi-attribute decision-making method [53] facilitates complex decision-making involving multiple criteria hierarchically connected/themed in clusters similar to PLACIT. Second, it allows not only the selection but also the relative prioritization and assessment of alternatives against the criteria used for decision-making [54]. Third, it can transform complex relationships between both qualitative and quantitative criteria used for decision-making into measurable quantitative relations [55]. Fourth, AHP provides ease of use over other MCDM methods, e.g., the analytic network process (ANP) [56–58].

Since it was developed by Thomas L. Saaty in the 1970s, AHP has become an increasing focus of attention in construction management research [59]. A review of 77 AHP-based papers across 8 journals revealed that AHP was mostly used with respect to risk management (11.69%) and sustainability (11.69%) research, with the greatest use in Asia (ibid). Examples from sustainability research include using AHP to inform: sustainable procurement of construction equipment in the Malaysian industry [60], sustainable design of industrial buildings with a focus on cost-effective solutions [61], material selection in green/sustainable buildings [58,62,63], and material selection to support design for deconstruction [64]. Other examples with direct links to construction CE include: identifying skills required by project managers in construction CE, evaluating strategies for bringing buildings into CE [65], and assessing barriers to implementing Industry 4.0 technologies in CE [66]. However, there appears to be a gap in the current literature for AHP to promote circular decision-making, rather than the wider consideration of sustainability, in real-life project situations. CAs using PLACIT have the potential to apply AHP to optimise circular proposal selection in building projects and complete the transition of the built environment to CE.

1.5. Aim and Objectives

This article revolves around the question of whether 'lifecycle circularity assessments (LCA) can be integrated into decision-making at the project front-end to improve proposal selection in building projects?'. This question responds to the current construction circular economy (CCE) knowledge gap in circularity assessment (CAs) being largely ignored during project front-end decision-making. Hence, this article aims to:

"Develop an integrated decision-making model based on the PLACIT framework to embed lifecycle circularity assessments (LCAs) in project front-end decision-making to facilitate the selection of circular proposals in building projects".

Achieving this aim requires the use of multiple-criteria decision-making (MCDM) and structured decision-making techniques. Two main objectives were set for this study:

1. To develop an MCDM model based on the PLACIT framework to facilitate the selection of circular proposals in building projects using AHP.
2. To establish priorities/weightings of the decision-making elements included in the proposed model, i.e., CTs and CIs, using feedback from building practitioners from an online questionnaire survey.

Figure 1 shows the steps followed to develop the AHP model and establish priorities/weightings of the decision-making elements, i.e., CTs and CIs. This article does not include the final step, i.e., "to use the proposed model to assess alternatives and select circular proposals in real-life building projects". This will be placed at the core of the next episode of this ongoing research about circularity assessment in building projects. Details about AHP decision-making model building, and data collection and analysis in the 'Circularity Assessment' questionnaire survey, are provided below.

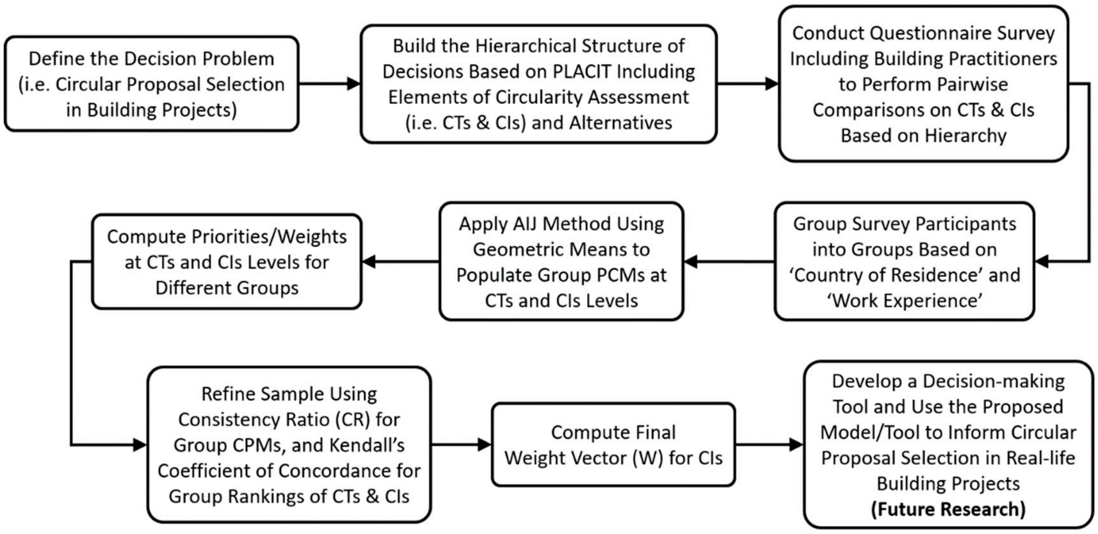


Figure 1. Steps followed to develop AHP decision-making model based on PLACIT.

2. Materials and Methods

2.1. Description of the Proposed AHP Model

Decision-making modelling using AHP starts with setting up a decision tree in which the elements of the decision are designed in a hierarchical order [67]. The proposed AHP model for 'circular' building proposal selection is organised at four main levels based on the PLACIT framework, Figure 2. The goal of this model, placed at the first level, is to 'select the most "circular" building proposal' using circularity themes (CTs), placed at the second level, and associated circularity indicators (CIs) grouped under relevant themes at the third level. Alternative proposals considered for the building project, placed at the fourth level, will be assessed for engaging with different CIs and subsequent contribution to the main goal of the model.

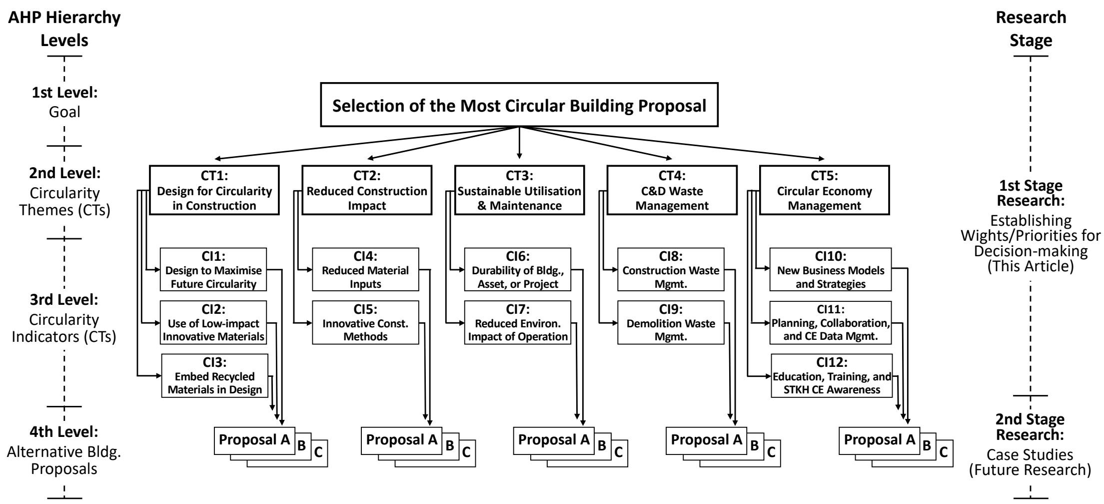


Figure 2. AHP hierarchical structure for the 'Selection of the Most Circular Building Proposal'.

Elements of decision-making at each level of the AHP model were compared against each other using a pairwise approach, and results were organised in pairwise comparison matrices (PCM), to establish priorities/weights for decision-making. Based on the decision tree in Figure 2, a 5 × 5 PCM referred to as MT was created to establish priorities amongst the five CTs at the second level, Equation (1). Each entry $M_{T\,i,j}$ in the matrix donates the average value of the ratio W_{Ti}/W_{Tj}; i.e., the weight of C_{Ti} compared with that of C_{Tj} as perceived by individual survey participants. Similarly, CIs at the third level classed under the same theme were locally compared, in pairs, with respect to their importance to the theme they are associated with. Subsequently, five extra PCMs were created for pairwise comparisons at the third level, each referred to as M_{Ix} for indicators in theme 'x' (two 3 × 3 PCMs for CT1's and CT5's indicators, and three 2 × 2 PCMs for CT2's, CT3's, and CT4's indicators).

$$M_T = \begin{array}{c|ccccc} & CT_1 & CT_2 & CT_3 & CT_4 & CT_5 \\ CT_1 & \frac{WT_1}{WT_1} & \frac{WT_1}{WT_2} & \frac{WT_1}{WT_3} & \frac{WT_1}{WT_4} & \frac{WT_1}{WT_5} \\ CT_2 & \frac{WT_2}{WT_1} & \frac{WT_2}{WT_2} & \frac{WT_2}{WT_3} & \frac{WT_2}{WT_4} & \frac{WT_2}{WT_5} \\ CT_3 & \frac{WT_3}{WT_1} & \frac{WT_3}{WT_2} & \frac{WT_3}{WT_3} & \frac{WT_3}{WT_4} & \frac{WT_3}{WT_5} \\ CT_4 & \frac{WT_4}{WT_1} & \frac{WT_4}{WT_2} & \frac{WT_4}{WT_3} & \frac{WT_4}{WT_4} & \frac{WT_4}{WT_5} \\ CT_5 & \frac{WT_5}{WT_1} & \frac{WT_5}{WT_2} & \frac{WT_5}{WT_3} & \frac{WT_5}{WT_4} & \frac{WT_5}{WT_5} \end{array} = \begin{array}{c|ccccc} & CT_1 & CT_2 & CT_3 & CT_4 & CT_5 \\ CT_1 & 1 & M_{T1,2} & M_{T1,3} & M_{T1,4} & M_{T1,5} \\ CT_2 & \frac{1}{M_{T1,2}} & 1 & M_{T2,3} & M_{T2,4} & M_{T2,5} \\ CT_3 & \frac{1}{M_{T1,3}} & \frac{1}{M_{T2,3}} & 1 & M_{T3,4} & M_{T3,5} \\ CT_4 & \frac{1}{M_{T1,4}} & \frac{1}{M_{T2,4}} & \frac{1}{M_{T3,4}} & 1 & M_{T4,5} \\ CT_5 & \frac{1}{M_{T1,5}} & \frac{1}{M_{T2,5}} & \frac{1}{M_{T3,5}} & \frac{1}{M_{T4,5}} & 1 \end{array} \quad (1)$$

Given the reciprocal nature of the PCM, Equation (2), and that all diagonal elements have a value of '1', Equation (3), the number of judgments (i.e., pairwise comparisons) required to populate each PCM can be calculated using Equation (4), suggested by Saaty and Vargas [68]. As a result, only ten pairwise comparisons had to be evaluated to populate M_T at the second level.

$$M_{Ti,j} = 1/M_{Tj,i}(i, j = 1, 2, 3, 4, 5) \quad (2)$$

$$M_{Ti,i} = 1(i = 1, 2, 3, 4, 5) \quad (3)$$

$$N = n(n-1)/2 \quad (4)$$

N is the number of judgments (pairwise comparisons) to populate each PCM
n is the number of elements being compared in the PCM

A modified rating scale based on the Saaty's 1–9 scale was developed, Table 3, to facilitate the two-way comparisons between pairs of CTs and CIs. The modified scale started with '1' in the middle and increased in both directions (9←1→9*). This allowed each question in the questionnaire survey to evaluate either Mi,j or Mj,i, and then establish the other value. For example, when comparing (X with Y): (1) indicates that X and Y are 'Equally Important', (9) indicates X is 'Extremely Important' compared with Y, and (9*) indicates Y is 'Extremely Important' compared with X.

Table 3. The modified scale (9←1→9*) used for pairwise comparisons between elements of circularity assessment (based on Saaty's 1–9 scale).

Intensity of Importance	Definition	Explanation
1	Equal Importance	The two elements contribute equally to circularity assessment
3 or 3*	Moderate Importance	An element is lightly favoured over another
5 or 5*	Strong Importance	An element is strongly favoured over another
7 or 7*	Demonstrated Importance	Dominance of an element is demonstrated in practice
9 or 9*	Absolute Importance	Absolute dominance of an element is affirmed at the highest level
2, 4, 6, 8	Intermediate Values	Used to compromise between judgements in data analysis

When comparing (X with Y), '9', for example, indicates X is 'Extremely Important' compared with Y, while '9*' indicates Y is 'Extremely Important' compared with X.

The survey involved multiple participants divided into groups based on their geographical distribution and work experience. Group scores can be aggregated using two methods: aggregation of individual judgments (AIJ), or aggregation of individual priorities (AIP) [69–72]. The former method, i.e., AIJ, is used when individuals act as a unit with a similar background and shared objectives [70]. The assumption that building practitioners involved in the survey were divided into groups with consistent geographical and experience backgrounds justified the use of AIJ for aggregating their scores. Individual judgements must then be aggregated using the geometric mean, Equation (5), to build the aggregated PCM for the group [70,73,74]. The weight vector (W) for each group can then be approximated, using Equation (6), by normalising the geometric means of the rows in the aggregated group PCM [68,75,76].

$$M_{i,j} = \sqrt[h]{\prod_{k=1}^{h} M_{i,j,k}}\,, \quad i, j = 1, \ldots, n \tag{5}$$

(where $M_{i,j,k}$ denotes entry for the same pairwise comparison (i,j) filled in by the k-th participant, n is the number of criteria for which pairwise comparisons are sought, and h is the number of participants involved)

$$W_i = \sqrt[n]{\prod_{j=1}^{n} M_{i,j}}\,, \quad i = 1, \ldots, n \tag{6}$$

(W is determined from the geometric means of the rows in the CPM).

Sample size and consistency of expert judgements in AHP research have been extensively discussed in the literature. Small samples are not uncommon in MCDM/AHP research [77,78], in which the focus is placed on the consistency of expert judgements [72] and the relevance of expert experience and assessment criteria to the context in which decision-making is practiced [79]. Consistent judgements from a small sample of experts, or even one single qualified expert, can be considered representative [59], whereas arbitrary answers from a large sample of participants may reduce consistency in group judgements [80].

Inconsistency in expert judgments is inevitable and measuring consistency remains a concern when using AHP [72]. The eigenvector method was used to check that inconsistency of expert judgements is within acceptable limits i.e., 'judgements are closer to being logically related than to being randomly chosen' [81]. The maximum eigenvalue λ_{max} is calculated for each PCM using Equation (7), after the weight vector (W) is determined. The consistency ratio (CR) can then be calculated using Equation (9); where CInd is the consistency index calculated from Equation (8), and RI is the random index obtained from Table 4, signifying the average CInd value of the randomly generated PCM matrix of the same size (RI = 1.12 for matrices with n = 5, RI = 0.58 for matrices with n = 3). The acceptable value is CR < 0.10, which means the PCM is reasonably consistent and established priorities/weights are trustworthy and can be used to make decisions using AHP.

$$M \times W = \lambda_{max} \times W\,; \tag{7}$$

M the Pairwise Comparison Matrix and W the Weight Vector

$$Consistency\ Index\ (CInd) = \frac{\lambda_{max} - n}{n - 1} \tag{8}$$

$$Consistency\ Ratio\ (CR) = \frac{Concistency\ Index\ (CInd)}{Random\ Index\ (RI)} \tag{9}$$

Table 4. Random indices (RI) from randomly generated matrices based on Duleba and Moslem [56].

n	1	2	3	4	5	6	7	8
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41

2.2. Data Collection and Analysis: The Questionnaire Survey

The 'Circularity Assessment' questionnaire survey was conducted online to establish priorities of elements of decision-making in the AHP model (i.e., weights and rankings

CTs and CIs) using feedback from building practitioners to facilitate circular building proposal selection. The survey included three main sections. First, the 'Cover Letter' introduced participants to the concept of circularity assessment using AHP and to the PLACIT framework proposed for circularity assessment of proposals in building projects. Second, the 'Personal Information Collection Form' captured relevant information about the survey participants (e.g., 'Country of Residence', 'Nature of Work' and 'Work Experience') to ensure the validity of research findings. Third, the 'Main Body' included six questions and aimed to establish priorities/weightings amongst elements of decision-making i.e., CTs and CIs. At the CTs level, 1 question including 10 pairwise comparisons, see Figure 3, was used to rate the relative importance of pairs of CTs to the circularity assessment of proposals in building projects using the modified Saaty's 1–9 scale. At the CIs level, five questions were used; each locally rates the relative importance of pairs of CIs classed under one of the five themes. Using Equation (4), the number of pairwise comparisons used in each question depended on the number of CIs classed under its associated theme: three pairwise comparisons for CT1's and CT5's indicators, and one pairwise comparison for CT2's, CT3's, and CT4's indicators.

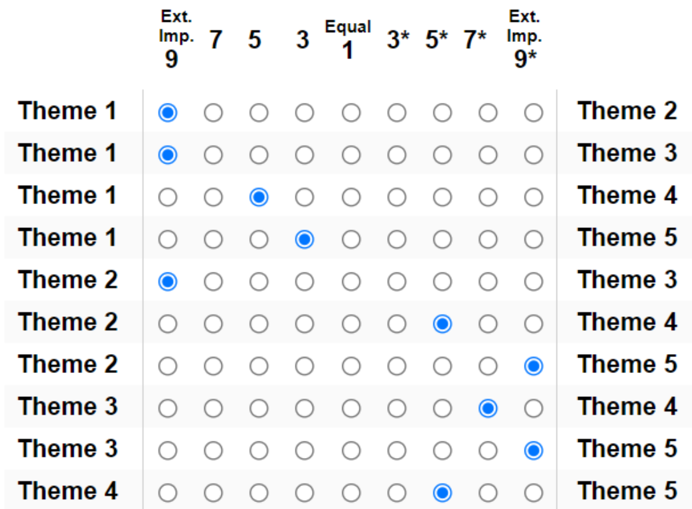


Figure 3. Example response to pairwise comparisons of the five CTs. When comparing (X with Y), '9', for example, indicates X is 'Extremely Important' compared with Y, while '9*' indicates Y is 'Extremely Important' compared with X.

Survey participants were divided into groups based on 'Country of Residence' and 'Work Experience', and individual judgments in each group were aggregated to populate group PCMs and establish group priorities for CTs and CIs. The significance of differences between the groups of participants regarding their priorities of CTs and CIs were statistically tested using Kendall's coefficient of concordance (Kendall's-tau), before the final weight vector (W) was determined for proposal selection in building projects. Compared with Spearman's rank correlation coefficient (Spearman's-rho), Kendall's-tau has a greater ability to handle data with tied ranks [82], higher robustness due to smaller gross error sensitivity (GES), and higher efficiency due to smaller asymptotic variance (AV) [83].

Kendall's-tau coefficient for two sets of rankings is calculated using Equation (10), and its value can range from (+1) if all pairs of rankings are concordant to (−1) if all pairs are discordant, while a value of (0) indicates no relationship. However, a negative value will indicate a 'lack of agreement' between the two groups and lead to the null hypothesis of 'no concordance' being directly accepted (i.e., Ho: $\tau \leq 0$). Table 5 below provides a possible interpretation of Kendall's-tau in the context of this study, where higher positive values indicate a stronger 'agreement'. Moreover, Kendall's-tau generally follows the normal distribution. Thus, the Z-score for positive coefficient values obtained from Equation (11) and the associated p-value from normal distribution table, with 95% confidence level, can be used to examine the null hypothesis of 'no concordance'.

$$\tau = \frac{n_c - n_d}{0.5\,N(N-1)} \quad (10)$$

τ = Kendall's-Tau coefficient
n_c = *Number of concordant pairs*, n_d = *Number of discordant pairs*
N = Number of the elements being ranked (N = 5 at CTs level, N = 12 at CIs level)

$$Z = \frac{3.\tau.\sqrt{N(N-1)}}{\sqrt{2(2N+5)}} \quad (11)$$

Z = z-score for Kendall's Tau coefficient

Table 5. Kendall's-tau agreement degree scale.

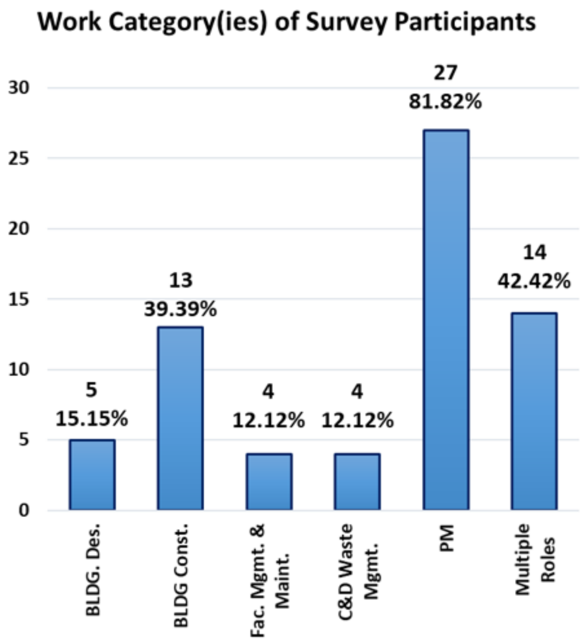
Kendall's-Tau Value Range	Interpretation
−1 to 0	Lack of agreement
0 to 0.20	Poor agreement
0.21 to 0.40	Fair agreement
0.41 to 0.60	Moderate agreement
0.61 to 0.80	Good agreement
0.81 to 1	Strong agreement

3. Results

3.1. Establishing Priorities for Circularity Assessment

The questionnaire was distributed to building practitioners on the Association for Project Management (APM) membership list (UK and Hong Kong branches), and to relevant LinkedIn groups. A total of 79 replies were received, 34 of which were excluded due to not providing full sets of judgements i.e., pairwise comparisons for CTs and CIs. Moreover, an approach of excluding inconsistent replies, i.e., those with randomly chosen judgements, was used to embed rigour in the decision-making process. Hence, further 12 replies were excluded due to their internal inconsistency before any further analysis was conducted. The final sample only included consistent feedback from 33 building practitioners. At a later stage, participants were grouped based on their 'Country of Residence', and aggregated judgments of individual groups were checked for consistency of views, i.e., agreement of group members about priorities of CTs and CIs. The distribution of 'Work Categories' of participants included, in descending order, 'Project Management' (27, 81.82%), 'Building Construction' (13, 39.39%), 'Building Design' (5, 15.15%), 'C&D Waste Mgmt.' (4, 12.12%) and 'Facility Mgmt. & Maintenance' (4, 12.12%), while nearly half of the sample had 'Multiple Roles' (14, 42.42%), see Figure 4.

'Country of Residence' was considered as a means of identifying countries with an interest in CA. Figure 5 revealed the UK (20, 60.61%) and China (11, 33.33%) to have building practitioners with sufficient interest in CA, while only 2 (6.06%) participants came from other countries. Survey participants were grouped into 'UK-based' and 'Non-UK', based on their 'Country of Residence', to compare views on CA of UK participants against those in the Non-UK group. Moreover, the former group was subdivided into 'UK Experts' and 'UK Non-experts', based on 'Work Experience', with the cut-off point being >5 years, to examine the influence of experience on their priorities of CTs and CIs.



Work Category	Participants (N = 33)	Percentage (N = 33)
Building Design	5	15.15%
Building Construction	13	39.39%
Facility Management & Maintenance	4	12.12%
Construction & Demolition Waste Mgmt.	4	12.12%
Project Management	27	81.82%
Multiple Roles	14	42.42%

Figure 4. Work Category(ies) and project role(s) of survey participants.

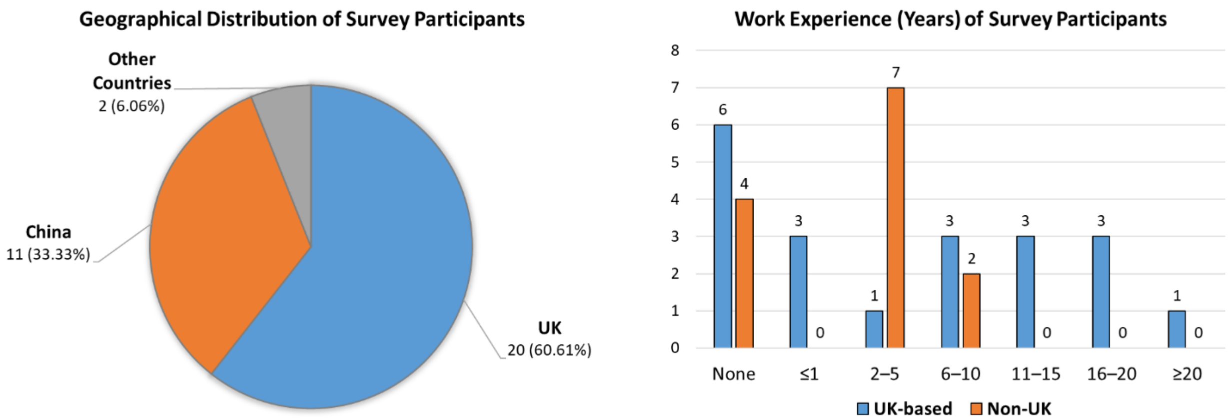


Figure 5. Distribution of survey participants 'Country of Residence' and 'Work Experience'.

The AIJ method was then employed using the geometric means of individual judgments in each group to populate group PCMs (pairwise comparison matrices) with aggregated judgements, at both the themes and indicators levels. This includes one aggregated PCM at the themes level and five at the indicators level for each group. For example, Table 6 shows the PCM with aggregated judgements and resulting weights for the 'UK Experts' group at the themes level. Consequently, the eigenvector method suggested by Saaty [81] was used to establish weights of CTs and CIs for each group individually to maintain group identity and compare views of different groups about circularity assessment.

Table 6. The aggregated PCM and resulting weights for 'UK Experts' at the themes level.

Eigenvector (Weight Vector)		Theme 1 0.5602	Theme 2 0.1066	Theme 3 0.0937	Theme 4 0.0757	Theme 5 0.1637
Theme 1	0.5602	1.0000	6.0491	6.0832	4.9856	4.3334
Theme 2	0.1066	0.1653	1.0000	2.7718	0.9577	0.4524
Theme 3	0.0937	0.1644	0.3608	1.0000	2.6480	0.6639
Theme 4	0.0757	0.2006	1.0442	0.3776	1.0000	0.4534
Theme 5	0.1637	0.2308	2.2106	1.5063	2.2056	1.0000

Group judgements were checked for consistency using the consistency ratio (CR), and differences between CTs and CIs weights/rankings from different groups were tested before the final weight vector (W) was determined for proposal selection in building projects. Despite the apparent agreement between the 'UK-based' and 'Non-UK' groups regarding their priorities at the CTs level, Table 7 reveals that judgements of the 'Non-UK' group (N = 13) were inconsistent (CR = 0.1379 > 0.1), i.e., randomly chosen. Thus, this group was excluded from the research sample and weights established from this group were not used for decision-making.

Table 7. Consistency checks of expert judgements in different groups of survey participants.

Code (CTi)	Non-UK (N = 13)		UK and Exp. > 5 (N = 10)		UK and Exp. ≤ 5 (N = 10)	
	Global Priority	Rank	Global Priority	Rank	Global Priority	Rank
CT1	46.29%	1	56.02%	1	27.67%	1
CT2	15.69%	3	10.66%	3	18.64%	4
CT3	12.70%	4	9.37%	4	9.04%	5
CT4	9.36%	5	7.57%	5	24.85%	2
CT5	15.96%	2	16.37%	2	19.81%	3
λ_{max}	5.6176		5.3990		5.2945	
CInd	0.1544		0.0997		0.0736	
CR	0.1379 > 0.1		0.0891 < 0.1		0.0657 < 0.1	

Differentiating the 'UK-based' group into two subgroups, 'UK Experts' (N = 10) and 'UK Non-experts' (N = 10), based on 'Work Experience' revealed two internally consistent (CR = 0.0891 < 0.1 for 'UK Experts', CR = 0.0657 < 0.1 for 'UK Non-experts') yet distinctive views about priorities for circularity assessment, i.e., weights and rankings of CTs and CIs. At the circularity themes (CTs) level, Figure 6 shows that CT1 'Design for Circularity in Construction' ranked first (R = 1) for both groups, acknowledging the role that design plays in achieving CE objectives. However, 'Experts' and 'Non-Experts' assigned significantly different weights (Experts: 56.02% vs. Non-Experts: 27.67%). Moreover, CT4 'C&D Waste Management' was ranked second by 'UK Non-experts' with a weight close to theirs for CT1 (24.85%, R = 2). This aligns with the study by Oliveira et al. [42] (p. 464), who asserted that existing circularity indicators 'focus on material recirculation and resource efficiency, not being capable of portraying the complex reality and possible trade-offs of circular systems'. Conversely, 'UK Experts' ranked CT4 last with a much lower weight (7.57%, R = 5) preceded by CT5 'CE Management' (16.37%, R = 2), CT2 'Reduced Construction Impact' (10.66%, R = 3), and CT3 'Sustainable Utilisation and Maintenance' (9.37%, R = 4). The weights and rankings of other themes (CT2, CT3 and CT5) also showed moderate differences between the two UK-based groups, reflecting different priorities for circularity assessments in building projects.

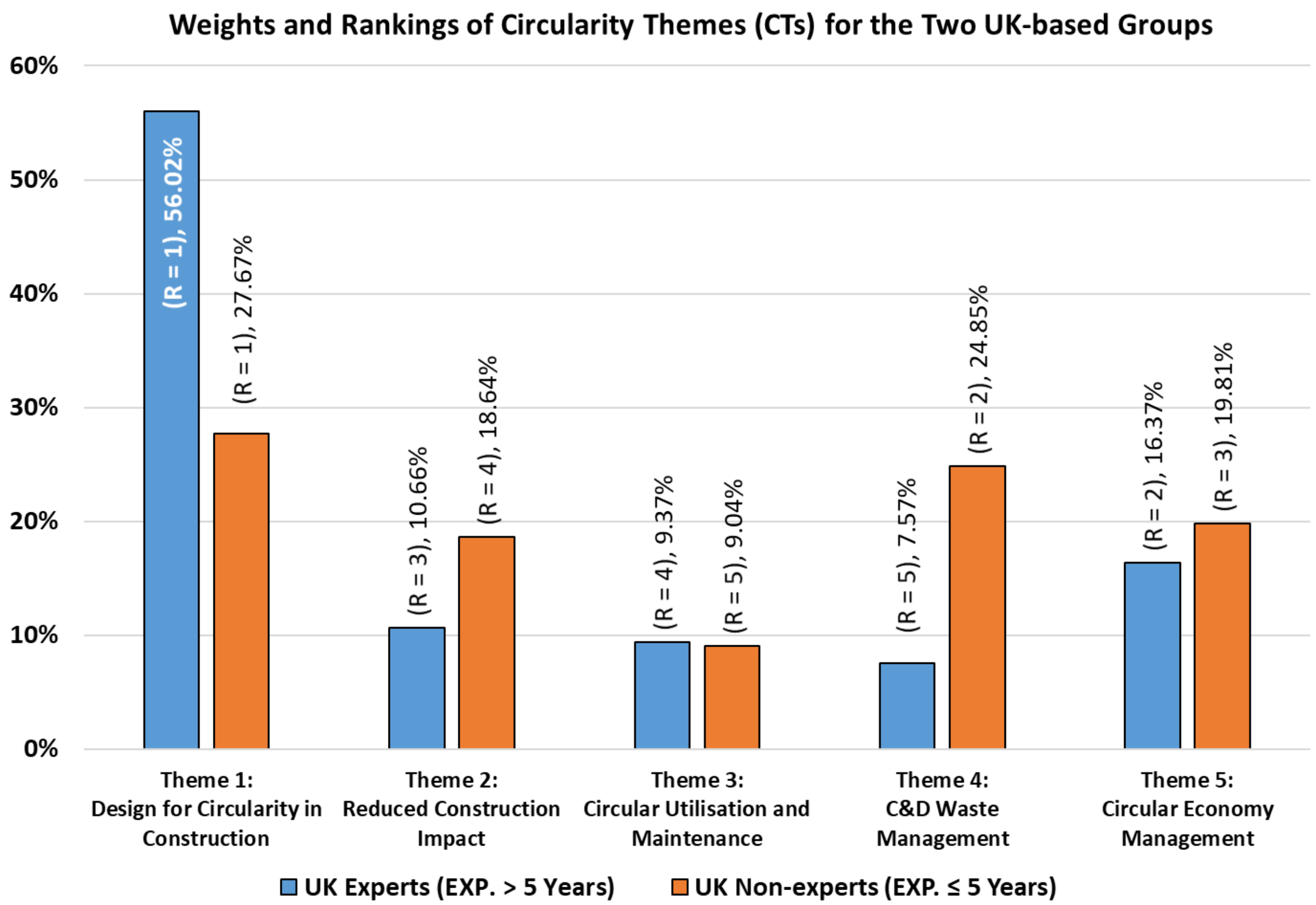


Figure 6. Weights/rankings of circularity themes (CTs) for the UK-based groups.

Similarly, Figure 7 reveals that the 'UK Experts' and 'UK Non-experts' groups had different priorities at the circularity indicators (CIs) level, especially for CT1 and CT4, in weight and ranking terms. Table 8 provides local weights, global weights, and global rankings for CIs established from the two UK-based groups. The results for indicators in CT1 related to circular building design showed that CI1 'Design Solutions to Maximise Future Circularity' ranked first (R = 1) for both groups. This aligns with the study by Cottafava and Ritzen [46], who noted that design for disassembly (DfD) criteria can be used as an accurate indicator for evaluating building circularity. However, once again there were significantly different weights (40.93% and 17.02%, respectively). Moreover, CI2 'Use of Low-impact Innovative Materials' ranked second for 'UK Experts' (9.27%, R = 2), whereas it ranked last for 'UK Non-experts' (3.41%, R = 12).

The weights and rankings of indicators in CT4 related to C&D Waste Management were also significantly different, with 'UK Experts' tending to score them extremely low (CI8: 5.42%, R = 8—CI9: 2.15%, R = 11), compared with 'UK Non-experts', who scored them extremely high (CI8: 16.46%, R = 2—CI9: 8.38%, R = 4). Other differences between the two 'UK-based' groups include weights and rankings for CI5 'Innovative Construction Methods' (Experts: 2.29%, R = 9 vs. Non: 11.82%, R = 3), and CI11 'Planning, Collaboration, and CE Data Management' (Experts: 2.16%, R = 10 vs. Non: 6.84%, R = 7), with 'UK Experts' tending to score these low compared with 'UK Non-experts'.

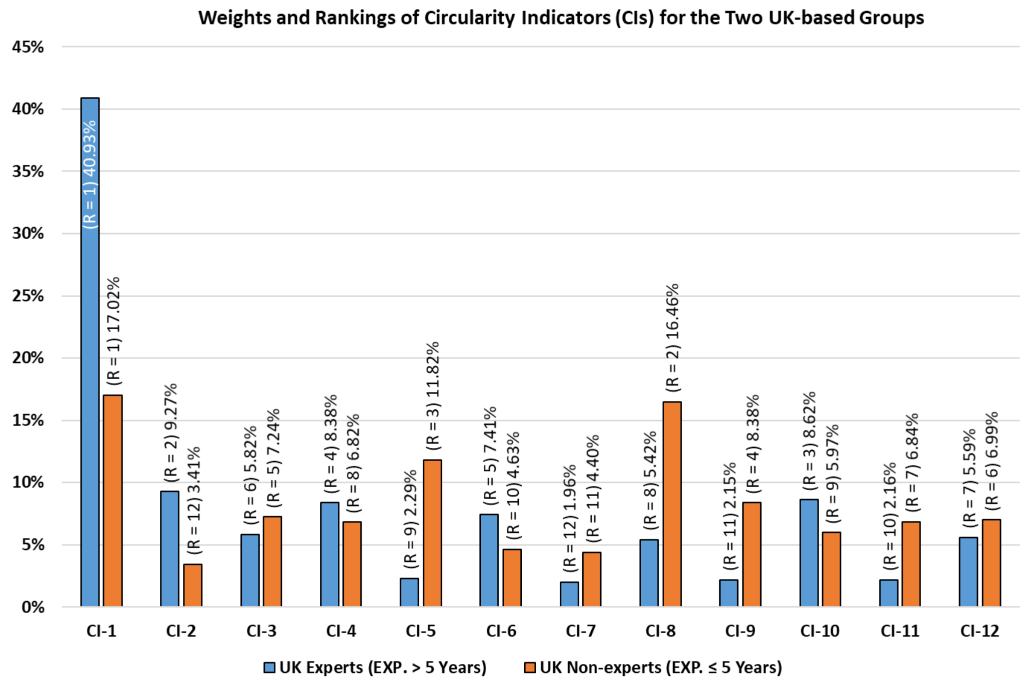


Figure 7. Weights/rankings for circularity indicators (CIs) for the UK-based groups.

Table 8. Local/global weights, and global rankings for CIs for the two UK-based groups.

CT Code	CI Code	Circularity Indicators (CIs)	UK and Exp. > 5 Years (N = 10)			UK and Exp. ≤ 5 Years (N = 10)		
			Local Priority	Global Priority	Global Rank	Local Priority	Global Priority	Global Rank
CT1	CI-1	Design Solutions to Maximise Future Circularity	73.05%	40.93%	1	61.52%	17.02%	1
	CI-2	Use of Low-impact Innovative Materials	16.55%	9.27%	2	12.32%	3.41%	12
	CI-3	Embed Recycled Materials in Design	10.39%	5.82%	6	26.16%	7.24%	5
CT2	CI-4	Reduced Material Inputs	78.56%	8.38%	4	36.57%	6.82%	8
	CI-5	Innovative Construction Methods	21.44%	2.29%	9	63.43%	11.82%	3
CT3	CI-6	Durability of Building, Asset or Project	79.06%	7.41%	5	51.29%	4.63%	10
	CI-7	Reduced Environmental Impact of Operation	20.94%	1.96%	12	48.71%	4.40%	11
CT4	CI-8	Construction Waste Management	71.58%	5.42%	8	66.26%	16.46%	2
	CI-9	Demolition Waste Management	28.42%	2.15%	11	33.74%	8.38%	4
CT5	CI-10	New Business Models and Strategies	52.65%	8.62%	3	30.16%	5.97%	9
	CI-11	Planning, Collaboration, and CE Data Mgmt.	13.21%	2.16%	10	34.54%	6.84%	7
	CI-12	Education, Training and Stakeholder CE Awareness	34.14%	5.59%	7	35.30%	6.99%	6

3.2. Influence of Work Experience on Priorities of CA

Earlier discussions revealed serious concerns about differences amongst UK participants based on their 'Work Experience' regarding their priorities for circularity assessment in building projects, and whether judgements of all UK participants can be included in decision-making. Kendall's coefficient of concordance (Kendall's-tau) was employed to assess the extent to which the two UK-based groups agree on their priorities of CTs and CIs, before the final Weight Vector (W) was determined for proposal selection in building projects.

Table 9 shows Kendall's-tau coefficient and associated z-score and *p*-value for priorities of the two UK-based groups at the CTs level. The positive value of coefficient at the CTs level (τ = 0.4000) indicated a 'fair agreement'; however, z-score and *p*-value indicated insignificant correlation between the two groups regarding their priorities of circularity themes (*p*-value > 0.05–95% confidence level) and, thus, the null hypothesis of 'no concordance' (H_0: $\tau \leq 0$) could not be rejected.

Table 9. Kendall's-tau coefficient of concordance for CTs level.

CT Code	'UK Experts' (Exp. > 5)	'UK Non-Experts' (Exp. $\leq$ 5)	n_c	n_d
CT1	1	1	4	0
CT5	2	3	2	1
CT2	3	4	1	1
CT3	4	5	0	1
CT4	5	2	-	-
		Sum	7	3

N = 5, τ = 0.4000, Z-score = 0.9798, *p*-value = 0.1636. Accepted null hypothesis of 'No Concordance' (H_0: $\tau \leq 0$), due to insignificant agreement between the two groups (*p*-value > 0.05).

At the CIs level, see Table 10, the negative value closer to zero ($\tau = -0.0909$) indicated a 'lack of agreement', i.e., discordance, between the two groups ($\tau < 0$), while no relationship could be established between their priorities of circularity indicators ($|\tau| \approx 0$); thus, the null hypothesis of 'no concordance' was directly accepted.

Table 10. Kendall's-tau coefficient of concordance for CIs level.

CI Code	'UK Experts' (Exp. > 5)	'UK Non-Experts' (Exp. $\leq$ 5)	n_c	n_d
CI-1	1	1	11	0
CI-2	2	12	0	10
CI-10	3	9	2	7
CI-4	4	8	2	6
CI-6	5	10	1	6
CI-3	6	5	3	3
CI-12	7	6	2	3
CI-8	8	2	4	0
CI-5	9	3	3	0
CI-11	10	7	1	1
CI-9	11	4	1	0
CI-7	12	11	-	-
		Sum	30	36

N = 12, τ = −0.0909, Z-score = N/A, *p*-value = N/A. Directly accepted null hypothesis of 'No Concordance' (H_0: $\tau \leq 0$) due to negative Kendall's-tau coefficient value ($\tau < 0$).

4. Discussion

4.1. Setting Priorities to Complete the Transition to CE

Findings from this study suggest the urgent need to reconsider priorities of CIs to complete the transition from the current situation described by the authors as a 'reuse/recycle economy' to a 'fully circular economy' in the built environment. First, on the one hand, 'aggregation of individual decisions, rather than deliberation to a consensus, can produce better decisions, and dissenting positions often are associated with insights being lost in consensus formation' [84] (p. 28); on the other hand, 'incorporating both rational and intuitive decision-making styles can strengthen the impact of knowledge creation processes on organisational performance' [85] (p. 111). The latter view implying creativity is a balance between 'open (divergent)' and 'closed (convergent)' thinking, despite its implications in the context of the 'the wisdom of crowds' phenomenon. Aligned with this view, intuitive group judgements in this study were checked for consistency using the consistency ratio (CR). Moreover, differences between the two 'UK-based' groups regarding their priorities of CTs and CIs were statistically tested using Kendall's coefficient of concordance, before the final weight vector (W) was determined for decision-making. i.e., proposal selection in building projects using AHP. Thus, judgements of the 'Non-UK' group were removed from decision-making due to lack of consistency, i.e., randomly chosen, and judgements of the 'UK Non-experts' group were removed due to lack of alignment with the new industry trends towards the transition to CE focused on waste prevention rather than the recirculation of materials. Based on earlier discussions about sample size and consistency of expert judgements in AHP research (see Section 2.1), the 'UK-experts' group (N = 10) was deemed highly consistent, rigorous, and sufficient for determining the final weight vector (W) of CIs for decision-making. Moreover, the approach adopted to refine the final research sample facilitated the embedment of the new industry trends towards priorities of the transition to CE in the final decision tree shown in Figure 8. However, weights established from the 'UK Non-experts' group can still be used, for comparison purposes only, to examine the effect of experience on decision-making in building projects and its implications for circularity assessment.

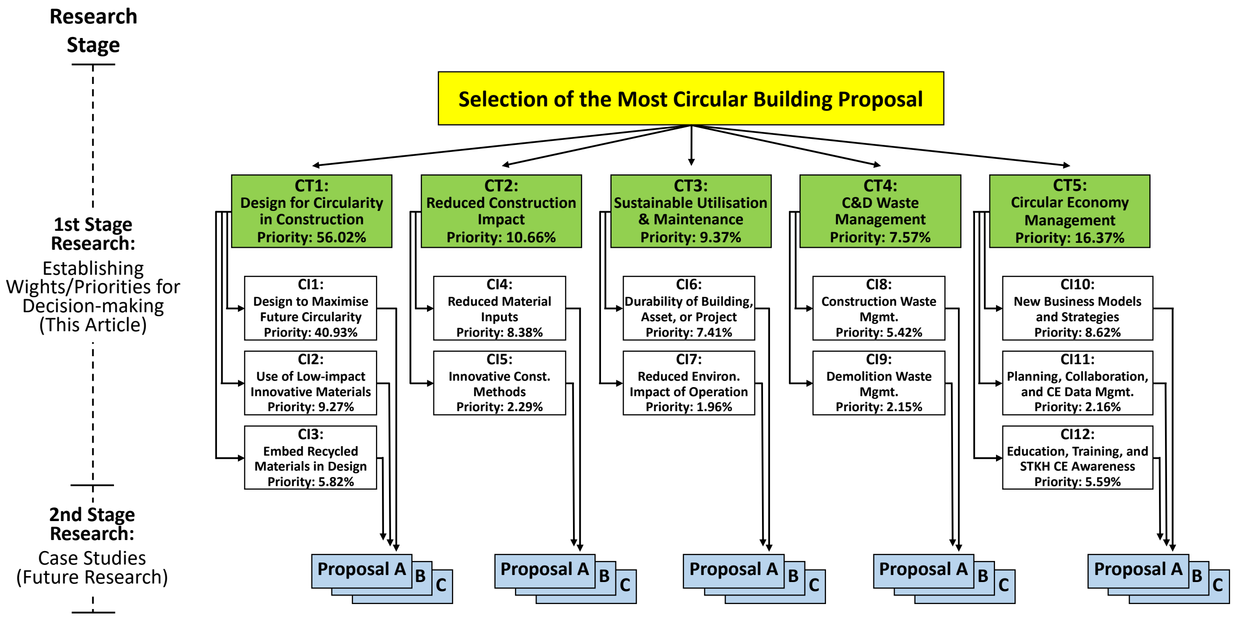


Figure 8. AHP MCDM model and final weights of CTs and CIs for use in circular proposal selection in building projects.

Second, the two different views amongst 'UK-based' building practitioners, based on their experience, about the priorities of circularity assessment denote the ongoing debate in the literature about the focus during the transition to CE, which raises concerns about CE governance in construction. The proactive behaviour of 'UK Experts' towards circularity assessment focused on 'front-end' circularity indicators relevant to 'Design for Circularity' and 'CE Management' is totally different from the reactive, or even passive, behaviour of 'UK Non-experts' focused on 'backend' circularity indicators relevant to 'Reduced Construction Impact' and 'C&D Waste Management'. For example, 'UK Experts' scored CI1 'Design Solutions to Maximise Future Circularity' very highly, representing the prolonged circular effects of design (40.93%, R = 1), and CI2 'Use of Low-impact Innovative Materials' (9.27%, R = 2) and CI3 'Embed Recycled Materials in Design' (5.82%, R = 6) relatively highly, which jointly represent the immediate effects of design. This finding from the 'UK Experts' group aligns with recent calls in the literature to view waste as 'design flaws' and 'design out waste', moving away from the traditional focus of CE being on waste management [14], and assertions that CE can create patterns of 'managing the waste by creating the proper design of materials' [24] (p. 25). Conversely, 'UK Non-experts' scored CI8 'Construction Waste Management' (16.46%, R = 2), CI5 'Innovative Construction Methods' (11.82%, R = 3) and CI9 'Demolition Waste Management' (8.38%, R = 4) highly. These findings from the two 'UK-based' groups suggested a lack of agreement between industry practitioners about the priorities of CAs, which can be traced back to differences in 'Work Experience'.

Third, this article argues that the transfer from the current 'reuse/recycle economy' to a 'fully circular economy' in the built environment requires reconsideration of priorities during the transition period, Figure 9. The findings from the survey support critiques that the CE literature is focused on waste management strategies and closing loops of construction materials, with not much attention paid to potentials of building design strategies for achieving objectives of CE [86], and the calls to view waste as 'design flaws' and aim to 'design out waste' as moving away from the traditional focus of CE on waste management [14]. Reflecting on 'what can be measured can be improved', this article argues that integrating circularity assessments (e.g., PLACIT) in building proposal selection at the project front-end in the context of lifecycle assessment (LCA) approach would help set the priorities to complete the transition to CE in the built environment.

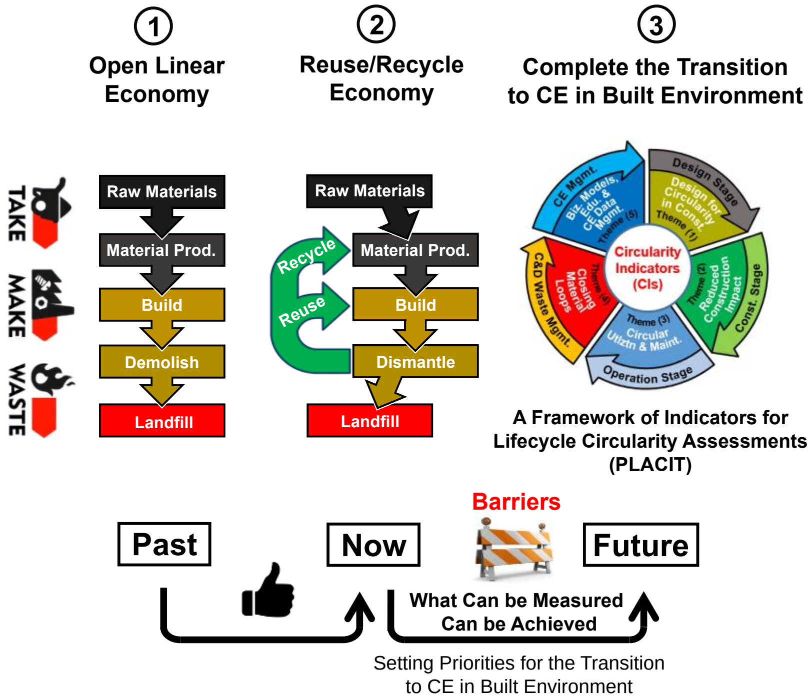


Figure 9. Partial transition and need to reset priorities to complete the transition to CE in built environment.

4.2. Theoretical Contribution

The theoretical contribution of this study, as part of an ongoing interest of authors about circularity metrics and indicators, is threefold. First, the proposed framework and decision-making model will help draw clear conceptual boundaries in the built environment research between sustainability rating systems (SRSs) in general, e.g., BREEAM in UK and LEED in US, and circularity assessments (CAs). While the former typically addresses building design attributes and aspects of retrofitting to improve energy consumption and carbon emissions during the operation stage, the latter is expected to focus on the circularity of building materials and enabling factors throughout the whole building lifecycle. Blurring of the conceptual boundaries risks creating unproductive dichotomies between the two concepts and falsifies claims of environmental achievements in the built environment. Hitherto, the construction CE literature has lacked a widely accepted and integrated framework for assessing the 'circularity' of construction activities.

Second, and related to the first, this study represents a pioneering example of a decision-making model to embed CAs in project front-end decision-making in the built environment. The model is based on an integrated framework of circularity indicators (CIs) previously developed and validated by the authors: the 'Project Life-cycle Assessment

Circularity Indicators and Themes (PLACIT)’. PLACIT was developed in response to urgent calls in the literature and industry for developing measures to assess the circularity of industry products (a building is considered a product here) using a more sectoral and integrated approach. It includes 12 high-level circularity indicators (CIs) encompassing relevant CE principles and covering all stages in a building lifecycle. The decision-making model proposed in this study was empirically calibrated, using the AHP algorithm and feedback from a highly consistent sample of experienced UK-based building practitioners, to embed industry priorities of CIs in decision-making practices to complete the transition to the CE in the UK built environment.

Third, and away from the technical side of Industry 4.0, this article argues that automated circularity assessments facilitated by MCDM tools and techniques have the potential to support digital CE initiatives, and thus provide a new pathway to, and extend understanding about, the digital transformation within the circular built environment. This assertion provides directions for future research in this field.

4.3. Practical Contribution

The decision-making model proposed in this study provides industry practitioners with a practical method to embed CAs in decision-making practices and informs selections of circular alternatives early in the building project. This will raise awareness amongst industry practitioners about CAs and ultimately support the transition to full circularity in the built environment. Future research will seek to apply the proposed model in real-life projects to identify qualitative and quantitative measures, e.g., footprint measures, for scoring building proposals against CIs included in the model; this would promote its use in practice. Moreover, using views of building practitioners to calibrate the decision-making model also provided an opportunity for those at the practice level to engage in decision-making and take part in directing the transition to CE, thereby addressing the criticism of minimal engagement with the operational (practice level) management of CE.

5. Conclusions

Reflecting on ‘what can be measured can be improved;, this article proposed a multiple-criteria decision-making (MCDM) model using the analytic hierarchy process (AHP) to embed circularity assessments (CAs) in project front-end decision-making to select circular proposals in building projects based on the ‘Project Lifecycle Assessment Circularity Indicators and Themes (PLACIT)’ framework by Abadi et al. [23]. The decision tree involved twelve circularity indicators (CIs) classed under five circularity themes (CTs); including four themes relevant to stages in a building lifecycle, while the fifth acknowledged CE management. The proposed framework and MCDM model will help draw clear conceptual boundaries in the built environment research between sustainability rating systems (SRSs) in general and circularity assessments.

The value of PLACIT for supporting MCDM using AHP in this study can be determined against shortcomings of the current CA literature discussed in Section 1.2. It adopts a holistic structure that supports systematic CAs throughout the whole building lifecycle using a framework of CIs. The stratified presentation of CIs in themes relevant to stages in a building lifecycle allows granular comparisons between alternative building proposals. This helps to avoid partial assessments and identify good ‘circularity’ aspects within ‘less circular’ proposals, which enables value optimisation of the selected proposal. Moreover, the stratified structure facilitates the use of AHP to integrate CAs in decision-making in building projects. This article argues that automated CAs and MCDM techniques have the potential to support digital CE initiatives, thus providing a new pathway to, and extending understanding about, the digital transformation within the circular built environment. Finally, the proposed model obviates the traditional pressure to optimise flows of individual materials by allowing operational decisions to be based on CAs of the whole product, i.e., the building, using CIs that cover all stages in a building lifecycle.

A questionnaire survey was distributed to building practitioners on the APM's membership list to establish priorities/weightings amongst elements of decision-making included in the proposed model i.e., CTs and CIs. Data analysis revealed variations among survey participants based on their geographical location and work experience. 'Non-UK' participants provided inconsistent judgements expressing a lack of awareness about the 'circularity assessment' concept, while 'UK-based' participants expressed two internally consistent yet distinctive views, based on their work experience, regarding their priorities of CAs both at the CTs and CIs levels. This raised concerns about CE governance and policies to achieve consensus amongst industry practitioners regarding their priorities during the transition to CE.

A more positive insight was the existence of a shared understanding amongst the UK participants of the immediate and prolonged effects of design for achieving circularity in building projects. However, caution is appropriate in that the evidence of a common acknowledgement of the relevance of design comprises significantly different weights applied by the survey groups based on their work experience, suggesting a positive association between work experience and views about waste being perceived as 'design flaws' and the need to 'design out waste'. Hence, there may be a value to considering this aspect when designing training/education packages and communication of priorities relevant to CAs.

Both the previous two points can be considered in the context of behavioural issues regarding priorities for CAs. There is evidence of differentiation between the two 'UK-based' groups, with work experience appearing to be the basis on which 'UK Experts' showed a proactive behaviour towards circularity assessment focused on 'front-end' CIs relevant to 'Design for Circularity', while 'UK Non-experts' evidenced reactive, possibly passive, behaviour focused on "back-end" CIs relevant to 'Reduced Construction Impact' and 'C&D Waste Management'. This behavioural aspect can be further considered in terms of the evidence found for engagement predominantly (UK participants) with indicators within the industry's comfort zone. This indicates what can be argued to be a supply–push behaviour (arguably representative of the industry's traditional mode of operation) focusing on aspirational 'Design Solutions to Maximise Future Circularity'. Whilst understandable in terms of the industry being at the 'early adopter' stage of its CE transition, not moving away from this behaviour as the transition journey unfolds presents a risk of missing opportunities from engaging with more demand–pull indicators, such as 'Use of Low-impact Materials' and 'Embed Recycled Materials in Design'.

The situation as depicted above reveals that the transition to CE in the built environment has only been partial and the industry can be described as having a 'recycle/reuse economy' rather than a 'circular economy'. The industry seems to adopt a narrow and reactive, rather than holistic and proactive, approach with a focus on 'closing loops of construction materials' rather than 'materials reduction' and 'system thinking'. This partial transition to CE, combined with the lack of consensus amongst industry practitioners regarding priorities of Cas, raises potential concerns about governance in construction CE and the moral obligations of actors at all industry levels to achieve consensus and complete the transition to CE. Completing the transition to CE involves meeting moral obligations and implementing system thinking at all industry levels (i.e., macro, meso and micro). This leads to a more general consideration of an approach to governance in which the moral and business cases are both present.

Finally, two recommendations are suggested for future research. The first is to apply the proposed AHP decision-making model in real-life project case studies and explore measures that industry practitioners can use to score building proposals against the model CIs. This will make the proposed model more appealing for use in industry. The second is to investigate localised views that may exist between different firms about their priorities for CAs and the possible impact on decision-making. This draws attention to the moral role that CE governance, at both the corporate and industry levels, should play in achieving industry consensus and setting industry priorities to complete the transition to CE.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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