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PRIORITIZING STRATEGIES FOR GREEN BUILDING CONSTRUCTION PROJECTS MANAGEMENT IN COASTAL TOWNS UNDER A NOVEL INTEGRATED Q-RUNG ORTHOPAIR FUZZY APPROACH

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Abstract. Sustainable development cannot be achieved without constructing green building projects, especially in coastal areas facing specific environmental challenges. Although there is extensive related research on green buildings, little attention has been paid to the Kenyan context. Our study seeks to fill this gap by not only assessing the barriers to implementing these projects but also providing strategic solutions to overcome them. Based on both the literature review and expert opinions, five barriers and five strategies were identified. Our study proposed a novel integrated approach that includes the q-rung Orthopair fuzzy (qROF) Pivot Pairwise Relative Criteria Importance Assessment (PIPRECIA) and Nearest Solution to References (REF), marking the first application of these techniques in combination. Furthermore, this study introduces the qROF-REF into decision-making literature for the first time. Our study results indicated that while high initial costs and insufficient government incentives are the main barriers to these project types, financial incentives are the most appropriate strategies to overcome them. Our study highlighted the crucial need to prioritize green building construction projects and thus contributes to their effective adoption.

Keywords: green building construction, barriers, strategies, Kenya, q-rung Orthopair fuzzy, pivot pairwise relative criteria importance assessment, nearest solution to references.

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1. Introduction

The construction sector is important for raising the standard of living, advancing society, and meeting essential needs. However, the construction activities, operations, and ecological footprint constitute a main issue. In view of the need for more responsible resource use and heightened environmental awareness, the Sustainable Development (SD) concept emerged as a notable focus approximately 30 years ago (Kasai & Jabbour, 2014). This shift prompted the sector to adopt sustainability practices, contributing to the emergence of Green Buildings (GB). Although there are various explanations of GBs amongst experts (Zhang et al., 2019), practices and designs are commonly prioritized to reduce environmental impact through resource efficiency. Additionally, there is a connection between improvements in the indoor environment and residents' health and well-being (Allen et al., 2015).

The change to sustainable construction has fostered the diminution of waste, improved the quality of the indoor environment, and expanded the usage of green resources (AlSanad, 2015). GBs improve environmental preservation considerably by reducing waste production and resource expenditure, enhancing the quality of water and air, and maintaining ecosystems (Kauskale et al., 2017). They appear as a powerful alternative to conventional buildings due to their benefits, such as operational cost reduction and the provision of low energy usage (Chaisaard & Taemthong, 2018). Typically, approximately 30% of general operating costs are attributable to energy expenses. There is a diminution of 55% in energy expenditure economizing and 30% in the costs of operation reduction (Zuo & Zhao, 2014). According to Kauskale et al. (2017) GBs offer various advantages, such as life-cycle production, reduced operational costs, and increased demand for durable services and materials. Leskinen et al. (2020) also emphasized how these types of buildings could generate excessive values of property and a superior flow of cash. Zuo and Zhao (2014) stated that social advantages can be provided by these buildings in addition to economic and environmental ones. Besides, the practices during their construction are socially viable and strengthen reliability in the urban landscape.

GB projects are important for enhancing sustainability; however, they encounter various location-dependent challenges. In Kenya, a country with a greater commitment to environmentally safe construction, few studies have examined the unique barriers that prevent the widespread implementation of GBs. Despite their many advantages, overcoming these barriers is key to ensuring effective implementation. The barriers faced are affected by conditions at the local level, making them distinct for each country (Komurlu et al., 2014).

Kenya, as a developing East African country, has demonstrated a powerful attraction to sustainability. As part of its Nationally Determined Contribution (NDC), the country intended to reduce its Greenhouse Gas (GHG) emissions by 30% five years ago, highlighting the crucial role of both the construction and building sectors, which together account for over 12% of the country's emissions (Sally, 2024). It has been noted that the country has progressively implemented GB practices in response to the decline in natural resources and the increasing need for SD (Burca, 2024). Yet barriers remain to managing GB construction projects, especially in coastal towns, as the country makes greater efforts towards durable growth. While there are considerable advantages to GB projects, various obstacles still restrict their wider adoption, which should be addressed to ensure greater acceptance (Otundo Richard, 2024).

Various studies examining barriers encountered in GB projects have been conducted. For instance, Hasan and Zhang (2016) indicated that incomprehension in project designation in Chinese GB projects is the main barrier. Chan et al. (2018) stated that the absence of information for GB materials and the huge costs of projects are considerable obstacles. At the same time, the absence of training for stakeholders is the main issue in South Africa (Mosly, 2015). Qian et al. (2015) pinpointed the absence of appropriate design instructions as the main barrier in Hong Kong. As for Kenya, the examination of barriers to handling GB projects in coastal towns is carried out (Otundo Richard, 2024). However, the identification of the most crucial barriers to these projects, along with the provision of strategic solutions to overcome them, to encourage SD in the country, is nonexistent. Moreover, most existing studies focus on identifying barriers qualitatively or in developed-country contexts, while limited attention has been paid to developing countries characterized by resource constraints, regulatory limitations, and high decision-making uncertainty. In particular, previous studies rarely provide an integrated computational decision-support framework that can simultaneously prioritize barriers and evaluate strategic solutions for GB construction projects under uncertainty. This creates an important research gap for policymakers and practitioners seeking reliable tools to support sustainable construction planning in Kenya and similar developing economies.

Allegedly, our study is the first to rank and assess barriers to handling GB construction projects in Kenyan coastal towns. It also intends to recommend the most appropriate strategic solutions to SD promotion in these zones. The lack of such a study has hindered further progress in the sustainable building sector. As a consequence, our study aims to answer the following research questions, with Kenya as the case study.

RQ1: Which barriers are hindering the GB construction in these specific towns of Kenya? This question aims to identify the main barriers hindering the advancement of GB projects in these areas, focusing on the effective barriers that restrict SD.

RQ2: How can the latest computational tools, like q-rung Orthopair fuzzy sets (qROFSs), assist in the choice of practical strategies for SD in these towns? This question identifies the main role of new decision support systems, such as qROFSs, in consolidating the decision-making process for strategies that enhance economic and environmental sustainability.

RQ3: In which manner can decision-making be ameliorated when assessing crucial barriers and choosing efficient strategies for GB projects in these towns, using an approach that integrates qROFSs-based pivot pairwise relative criteria importance assessment (PIPRECIA) and Nearest Solution to References (REF) methods? This question investigated how combining decision-making schemes, particularly the PIPRECIA-REF approach, can enhance precision and effectiveness in handling barriers and in pinpointing appropriate strategies for SD in these areas.

The motivations of our study are as follows. The MCDM approaches with q-ROFSs have been adopted in decision-making studies, yet they have not been applied to prioritize GB construction projects in coastal towns of a developing country. The most attractive aspect of q-ROFSs is that they offer a wider range of membership and non-membership degrees, giving decision-makers greater freedom to express their legitimate opinions. This characteristic is particularly important in GB construction project evaluation, where experts' judgments are often uncertain, subjective, and influenced by economic, environmental, technical, and social considerations. Therefore, the use of q-ROFSs enables a more flexible and reliable representation of expert evaluations compared with traditional fuzzy environments. Despite these advantages, the application of q-ROFS-based decision models in sustainable construction and GB project management remains limited in the current literature. Existing approaches often fail to capture the complexity of conflicting economic, environmental, technical, and regulatory factors simultaneously. Consequently, there is a need for a more robust and integrated framework that can handle uncertainty and improve the reliability of strategic decision-making in GB construction projects.

Determining criteria weights is an important step in Multi-Criteria Group Decision-Making (MCGDM) problems. In the literature, criteria-weighting methods are divided into two categories: objective and subjective. In the objective method, the weights of the criteria are determined from the data in the decision matrix using mathematical models and scores, without considering experts' preferences, whereas in the subjective method, the criteria weights are obtained using experts' opinions (Bouraima et al., 2024). As a subjective method, the Pivot Pairwise Relative Criteria Importance Assessment (PIPRECIA) tool was first developed by Stanujkic et al. (2017). It preserves the merits of the SWARA model by avoiding its limitations. The key benefit of the PIPRECIA model is that it allows the criteria to be estimated with no prior sorting by importance. The integration of q-ROFSs with the PIPRECIA method enhances experts' ability to express uncertain preferences while generating more realistic and consistent criterion weights in complex GB project environments. Compared with conventional weighting approaches, the proposed qROF-PIPRECIA framework provides greater flexibility in handling ambiguous expert judgments and reduces inconsistencies arising from subjective evaluations. This is particularly important in GB construction decision-making, where expert opinions may vary considerably due to economic and sustainability-related trade-offs.

The Nearest Solution to References (REF) method was proposed by Aytekin (2020) to provide solutions based on distance and references for problems, including different data structures. In this study, a new extension of REF-II under q-ROFSs will be proposed. It is possible to identify references in REF as points or intervals. Furthermore, the REF extension provided in this study does not cause the rank reversal problem. In this context, a robust methodology will be proposed to enable the effective collection and processing of evaluations from experts unfamiliar with MCDA methods.

The integration of qROF-PIPRECIA and qROF-REF provides a comprehensive decision-making framework in which PIPRECIA determines the relative importance of barriers and strategic criteria, while REF ranks alternative strategies by their closeness to ideal reference solutions. Such integration improves the stability, reliability, and interpretability of the decision-making process, particularly in complex sustainability-related problems characterized by uncertainty and conflicting criteria. Moreover, the integrated framework helps reduce inconsistencies in expert judgments and enhances the robustness of the final ranking through complementary weighting and evaluation mechanisms. Accordingly, the proposed integrated qROF-PIPRECIA-REF framework advances the state of the art by combining advanced uncertainty modeling with a robust ranking mechanism tailored to the evaluation of GB construction projects in developing-country contexts. Unlike previous studies that applied standalone MCDM methods, this study provides a comprehensive decision-support tool that simultaneously addresses uncertainty, rank stability, and strategic prioritization.

The major contributions of this study are as follows:

- To assess the most critical barriers to GB construction using an integrated model and provide a comprehensive framework for selecting strategic solutions to overcome them, thereby fostering the sustainable development of Kenya's coastal towns.
- To propose a new fuzzy decision methodology based on q-ROFS to evaluate and rank the strategic solutions for the sustainable development of coastal towns of Kenya.
- To introduce and integrate qROF-PIPRECIA and qROF-REF into a unique methodology employed for decision problem evaluation.
- To assess the validity of our proposed approach through changes in the criterion weight coefficients, an analysis of the rank reversal problem's presence, and comparative analyses.
- To make recommendations for addressing barriers to GB construction of coastal towns employing the proposed qROF- PIPRECIA- REF-based methodology.

The remaining part of the study is divided into five sections. Section 2 presents the literature review; Section 3 outlines the methodology; Section 4 presents the case study, which is an application; Section 5 provides the main discussions related to the findings; and Section 6 presents the conclusions and future recommendations.

2. Literature review

2.1. Barriers to the adoption of GB construction projects

The adoption of GB principles by stakeholders in the construction industry has not been widespread, likely due to several barriers. A literature review was conducted to identify the barriers encountered in GB projects in as many countries as possible. For instance, Mogaji et al. (2025) adopted a quantitative approach to evaluate barriers to implementing new building materials for durable construction in the Nigerian construction sector. Thach et al. (2026) evaluated the performance of green construction fields through a fuzzy synthetic assessment. Ikingura et al. (2025) explored the main barriers and key strategies for implementing green building in Tanzania. Mushi et al. (2025) modeled and forecasted influential parameters for the intention to implement green buildings in Tanzania. Liu et al. (2026) identify the drivers of adoption of the green housing concept in Chinese cities. Chong et al. (2026) examine the barriers and strategies to promote the adoption of green residential buildings in Malaysia. Taherkhani (2024) evaluates the barriers to the adoption of green buildings in Iran. Komurlu et al. (2024) examine which barriers affect the construction of green building projects in Turkey. Yussif et al. (2025) conducted an extensive review of risk assessment in green building construction projects. Hamid et al. (2023) add the issues of increased construction and maintenance costs.

2.2. MCDM-related studies on GB construction projects

A GB can effectively use sustainable materials in its construction, provide a healthy interior environment with minimal pollutants, and have a water-efficient landscape design that uses native vegetation that grows well without extra watering (Wong et al., 2016). Evaluating green construction is a Multi-Criteria Decision-Making (MCDM) approach. Therefore, various scholars applied it in their studies. For example, Kamranfar et al. (2022) applied an integrated decision-making model to analyze barriers related to green construction development. Gohari et al. (2025) adopted a best-worst method to evaluate barriers for adopting green building technologies in Mashhad residential buildings. Zhou et al. (2024) analyze the complex relationships among customer needs, GB design technical features, and the optimal allocation of GB design index weights. Abdel-Basset et al. (2021) focus on the dimensions and indicators of sustainable design for GBs in developing countries to achieve the positive dimensions of building sustainability. Table 1 presents a comparative analysis of our current study with previous ones.

Table 1. A comparative analysis of previous studies with current one on green building projects

Authors	Objective	Methodology	Uncertainty environment	Location	Limitation	Contribution
Mogaji et al. (2025)	Barrier related to the implementation of new building materials for sustainable construction	Quantitative approach	Deterministic	Nigeria	Focused mainly on identifying barriers without strategic solutions	Provides an integrated framework for prioritizing barriers and evaluating strategic solutions simultaneously
Thach et al. (2026)	Performance assessment of green construction fields	Fuzzy synthetic assessment	Fuzzy environment	Vietnam	Limited to performance assessment without integrated ranking of alternatives	Introduces integrated qROF-PIPRECIA-REF methodology for weighting and ranking under uncertainty
Ikingura et al. (2025)	Barriers and strategies for GB implementation	Qualitative analysis	Deterministic	Tanzania	Did not incorporate advanced computational decision-support tools	Applies the qROFS-based MCDM framework to improve the reliability of expert evaluations
Mushi et al. (2025)	Forecasting influential parameters for GB implementation	Modeling and forecasting techniques	Deterministic	Tanzania	Focused on forecasting rather than strategic prioritization of barriers and solutions	Simultaneously evaluates barriers and ranks sustainable strategies
Liu et al. (2026)	Drivers for adopting green housing concepts	Statistical analysis	Deterministic	China	Concentrated on adoption drivers rather than barrier prioritization	Evaluates critical barriers and proposes strategic solutions for GB projects
Chong et al. (2026)	Barriers and strategies for green residential buildings	Survey-based analysis	Determinsitic	Malaysia	Lack of integrated uncertainty modeling and ranking mechanism	Uses qROFSs to capture ambiguity and uncertainty in expert judgments
Taherkhani (2024)	Barriers to GB adoption	Qualitative assessment	Determinsitic	Iran	Did not apply advanced MCDM techniques for strategic evaluation	Introduces an integrated weighting and ranking framework under the qROFS environment
Komurlu et al. (2024)	Barriers affecting GB construction projects	Descriptive analysis	Determinsitic	Turkey	Limited to barrier identification without a robust prioritization approach	Provides comprehensive prioritization of barriers and strategic alternatives
Yussif et al. (2025)	Risk assessment in GB construction projects	Extensive literature review	Determinsitic	General context	Focused on risk review without a computational evaluation framework	Develops practical decision-support methodology for sustainable GB planning
Hamid et al. (2023)	Additional construction and maintenance costs in GB projects	Cost-related assessment	Deterministic	Malaysia	Focused mainly on economic issues without integrated sustainability evaluation	Considers economic, environmental, technical, and strategic dimensions simultaneously
Kamranfar et al. (2022)	Green construction barriers	İntegrated MCDM model	Conventional fuzzy environment	Iran	Did not address rank reversal and advanced uncertainty modeling	Integrates qROF-PIPRECIA and qROF-REF with rank stability analysis

End of Table 1

Authors	Objective	Methodology	Uncertainty environment	Location	Limitation	Contribution
Gohari et al. (2025)	Barriers to adopting GB technologies	Best Worst Method (BWM)	Crisp environment	Iran	Relied on a single weighting method without an integrated ranking mechanism	Combines criteria weighting and alternative ranking within one framework
Zhou et al. (2024)	GB design optimization and customer needs	MCDM analysis	Deterministic	China	Focused on design optimization rather than sustainability barriers	Evaluates practical barriers and strategic solutions for sustainable development
Abdel-Basset et al. (2021)	Sustainable design indicators for GBs	Advanced decision model	Fuzzy environment	Developing countries	Did not apply qROFS-based REF methodology	Extends REF-II under the qROFS environment for the GB project evaluation
Our study	Barriers and strategic solutions for GB construction projects	Integrated qROF-PI-PRECIA-REF framework	q-rung Orthopair Fuzzy Sets (qROFSs)	Kenyan coastal towns	Addresses limitations of previous studies by integrating uncertainty modeling, criteria weighting, strategic ranking, and rank reversal analysis within one framework	Provides a novel and comprehensive decision-support framework tailored for sustainable GB construction projects in developing-country contexts

2.3. Research gaps

The following are the gaps of our study: a) no study prioritizes the strategies for GB construction projects in coastal towns of Kenya from the MCDM outlook. Our study does so by proposing strategies through a methodical ranking approach. b) There is no available scheme that combines the PIPRECIA and REF approaches under the qROFS environment to explore the barriers to GB construction projects and recommend strategies to overcome them.

3. Methodology

This part of our study has two sub-sections.

3.1. Preliminaries

Since the beginning of a Fuzzy Set (FS) (Zadeh, 1965) it has been fruitfully utilized to handle vagueness/ambiguity in the data. In FS, an element is characterized by the membership value. Afterward, Atanassov (2016) generalized the FS to an Intuitionistic Fuzzy Set (IFS), whose elements have the Membership Value (MV) and Non-membership Value (NV) with their sum being ≤1. As a generalized form of FS, the conception of a Pythagorean Fuzzy Set (PFS) by Yager (2015) has been introduced in which the sum of MV and NV is ≥ 1, but the sum of their square is ≤ 1. Further, q-ROFS has emerged as an advanced extension of FS, offering greater practicality and robustness than FS, IFS, and PFS for describing uncertainty in numerous decision-making issues. The preliminaries of the q-rung Orthopair fuzzy sets (Alkan & Kahraman, 2021; Aytekin et al., 2024; Du, 2018; Liu & Wang, 2018; Wei et al., 2018; Yager, 2016) are shown in Appendix A.

3.2. The adopted qROFS- PIPRECIA- REF approach

The of our proposed qROFS- PIPRECIA- REF approach (Aytekin et al., 2024; Liu & Wang, 2018; Mishra et al., 2023) are indicated in Appendix B.

Since the PIPRECIA approach has been developed, it has been applied for various studies such as railway systems ranking (Bouraima et al., 2022), road construction project delay (Stević et al., 2022), choice in artificial intelligence algorithm (Popović et al., 2025), green supplier selection (Đalić et al., 2020), and financial reporting platforms (Mladenovic et al., 2023), and different uncertain environment such as plithogenic (Ulutaş et al., 2021), interval-valued Fermatean fuzzy (Görçün et al., 2024), intuitionistic fuzzy (Ayyildiz & Erdogan, 2024), Fermatean fuzzy (Yildirim et al., 2024), rough fuzzy (Stević et al., 2021), interval rough (Na et al., 2024), and grey (Stanujkić et al., 2021). In this study, the q-ROF-PIPRECIA approach is adopted for the first time to assess the weights of criteria for green building construction projects.

Since its establishment, the REF approach has been extended to different conditions and data types. Among these, REF-I includes process steps for solving problems that include qualitative criteria and mixed structures (Aytekin & Durucasu, 2021). REF-II contains a structure that provides a solution to the rank reversal problem (Kırda & Aytekin, 2024). REF-III enables efficiency evaluation for decision-making units (Aytekin et al., 2023a). REF-Sort is used for the classification of options (Aytekin et al., 2023b). Figure 1 indicates the flowchart of our proposed methodology.

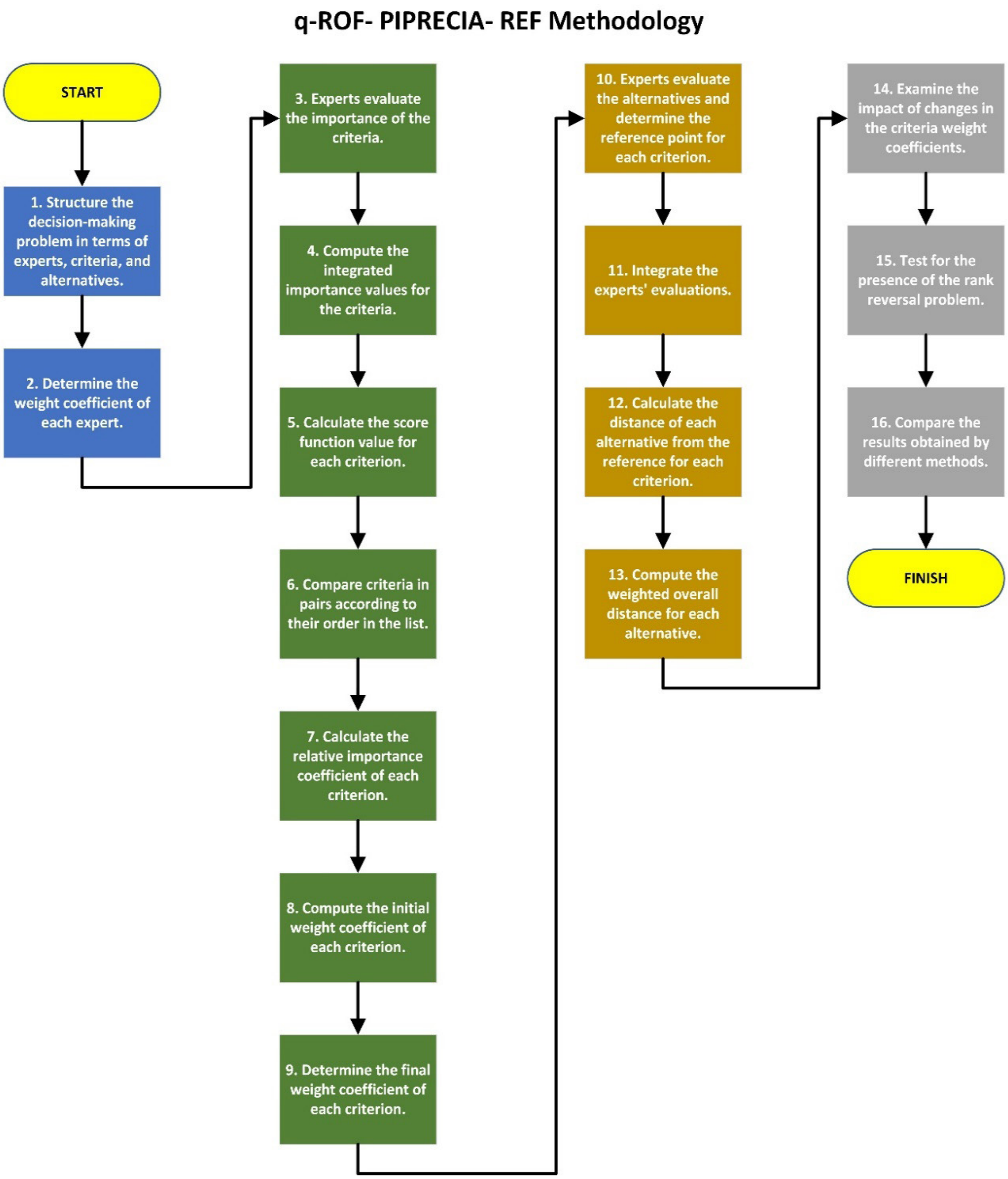

Figure 1. The proposed methodology

4. Application (case study)

Three sub-sections are identified in this part.

4.1. Criteria and alternatives definition

In our study, five barriers (criteria) to handling GB construction projects, along with five strategic alternative solutions to enhance sustainable development in these areas of Kenya, are provided in Table C1 (Otundo Richard, 2024; Saka et al., 2021; Tran, 2020) in Appendix C. To ensure a systematic and transparent identification of these criteria and alternatives, the selection process followed a structured two-stage approach. First, a comprehensive literature review of sustainable construction and green building implementation in developing countries was conducted to identify commonly reported barriers and potential strategic interventions. This ensured that the initial list of criteria and solutions reflects established theoretical and empirical findings in the field. Second, a panel of domain experts was consulted to validate, refine, and contextualize these items to the Kenyan construction context. During this validation process, experts were asked to assess the relevance, clarity, and practical applicability of each identified factor, and adjustments were made based on consensus to ensure local relevance and realistic decision-making. This combined literature-expert triangulation approach enhances the robustness, reliability, and contextual validity of the selected criteria and alternatives used in this study. The process of inviting experts is important for complex decision-making evaluations, assessing existing barriers, and providing solutions and strategies. Our study invited nine experts to provide us with the data. The selection of these experts is based on specific criteria, including being either an academician or an industry professional with at least 5 years of experience. Table C2 provides background information on these experts in Appendix C. Personal online meetings with these experts are conducted after agreement on their availability.

4.2. Results for strategies prioritization for GB construction project management

Our study focuses on prioritizing strategies for GB construction project management in Kenya's coastal towns using a QROFS-PIPRECIA-REF approach. To determine the weights of the experts, the linguistic terms given in Table B1 were used. At this point, the evaluations of the experts $E_1,...,E_9$ were given high importance. As a result, the weight value of each expert was calculated as $\lambda_k = 0{,}1111$. The experts' linguistic evaluations of the importance levels of the criteria are presented in Table D1 in Appendix D. To determine the experts' weights, the linguistic terms in Table B1 were used. At this point, the evaluations of the experts $E_1,...,E_9$ were given high importance. As a result, the weight value of each expert was calculated as $\lambda_k = 0{,}1111$. The experts' linguistic evaluations of the criteria's importance levels are presented in Table D1.

After integrating the evaluations of the criteria, q-ROF-PIPRECIA analyses were completed, yielding the results in Table D1. To aggregate the experts' evaluations, Eq. (A9) was used, where q = 3. For example, the linguistic evaluations made by each expert for C1 and their corresponding q-ROFN are presented below.

$$\text{Experts' evaluations} = \frac{\boldsymbol{C}1}{\dfrac{\boldsymbol{E}1,\boldsymbol{E}2,\boldsymbol{E}3,\boldsymbol{E}4,\boldsymbol{E}5,\boldsymbol{E}6,\boldsymbol{E}7,\boldsymbol{E}8,\boldsymbol{E}9}{(M,H,VH,VH,H,H,VH,VH,VH)}} = \frac{\dfrac{\boldsymbol{C}1}{\iota_{j=1}^{(k)} = \left(\mu_{j=1}^{(k)},\nu_{j=1}^{(k)}\right)}}{\left\langle \begin{matrix}(0.5,0.5),(0.8,0.2),(0.95,0.05),(0.95,0.05),(0.8,0.2),\\(0.8,0.2),(0.95,0.05),(0.95,0.05)(0.95,0.05)\end{matrix}\right\rangle}.$$

The q-ROF aggregation value for C1 is calculated as follows:

$$q-ROFWA_{j=1} = \left(\sqrt[q=3]{1-\prod_{k=1}^{l=9}\left(1-\mu_{jk}^{q=3}\right)^{\lambda_k=0.1111}},\prod_{k=1}^{l=9}\left(\nu_{jk}\right)^{\lambda_k=0.1111}\right)$$

$$\iota_{j=1} = \left(\mu_{j=1},\nu_{j=1}\right) =$$

$$\left(\begin{matrix}\sqrt[3]{\begin{matrix}1-[\left(1-0.5^3\right)^{0.1111}x\left(1-0.8^3\right)^{0.1111}x\left(1-0.95^3\right)^{0.1111}\\ x\left(1-0.95^3\right)^{0.1111}x\left(1-0.8^3\right)^{0.1111}x\left(1-0.8^3\right)^{0.1111}\\ x\left(1-0.95^3\right)^{0.1111}x\left(1-0.95^3\right)^{0.1111}\\ x\left(1-0.95^3\right)^{0.1111}]\end{matrix}},\\ 0.5^{0.1111}x0.2^{0.1111}x0.05^{0.1111}x0.05^{0.1111}x0.2^{0.1111}x0.2^{0.1111}\\ x0.05^{0.1111}x0.05^{0.1111}x0.05^{0.1111}\end{matrix}\right)$$

$$\iota_{j=1} = (0.9033, 0.1025).$$

The score function value of $\iota_{j=1}$ is computed as follows:

$$\mathcal{S}\left(\iota_{j=1}\right) = \frac{1}{2}\left(0.9033^{q=3} - 0.1025^{q=3} + 1\right) = 0.8680.$$

C1 is the base criterion for the qROF-PIPRECIA application, then $c_{j=1} = 1$. When we compare $\mathcal{S}\left(\iota_{j=2}\right)$ and $\mathcal{S}\left(\iota_{j=1}\right)$, it is seen that $\mathcal{S}\left(\iota_{j=2}\right) < \mathcal{S}\left(\iota_{j=1}\right)$. For C2, c_2, the relative importance coefficient (ζ_2), the initial weight coefficient ϑ_2, and the weight coefficient w_2 are computed as follows, respectively.

$$c_2 = 1 + \mathcal{S}\left(\iota_{j=2}\right) - \mathcal{S}\left(\iota_{j=1}\right) = 1 + 0.7765 - 0.8680 = 0.9085;$$

$$\zeta_2 = 2 - c_j = 2 - 0.9085 = 1.0915;$$

$$\vartheta_2 = \frac{\vartheta_{j=1}}{\zeta_{j=2}} = \frac{1}{1.0915} = 0.9162;$$

$$w_2 = \frac{\vartheta_2}{\sum_{j=1}^{5}\vartheta_j} = \frac{0.9162}{1+0.9162+0.9344+0.8618+0.8529} = 0.2007.$$

Table 2. Evaluations of experts regarding the importance of criteria

	C1	C2	C3	C4	C5
$\iota_j = \left(\mu_j,\nu_j\right)$	(0.9033, 0.1025)	(0.8251, 0.2053)	(0.8422, 0.1749)	(0.7614, 0.2608)	(0.7535, 0.2935)
$\mathcal{S}\left(\iota_j\right)$	0.8680	0.7765	0.7960	0.7118	0.7013
c_j	1.0000	0.9085	1.0195	0.9158	0.9895
ζ_j	1.0000	1.0915	0.9805	1.0842	1.0105
ϑ_j	1.0000	0.9162	0.9344	0.8618	0.8529
w_j	0.2190	0.2007	0.2047	0.1888	0.1868
Rank	1	3	2	4	5

Table 3. The integrated q-ROF decision matrix and the q-ROF reference values

	C1	C2	C3	C4	C5
S1	(0.9240, 0.0825)	(0.7677, 0.2758)	(0.8985, 0.1091)	(0.8181, 0.2158)	(0.6842, 0.3826)
S2	(0.5658, 0.4687)	(0.8773, 0.1363)	(0.6641, 0.3481)	(0.8219, 0.2123)	(0.7035, 0.3280)
S3	(0.8044, 0.2420)	(0.8409, 0.1664)	(0.6878, 0.3653)	(0.9156, 0.0926)	(0.7665, 0.2823)
S4	(0.8353, 0.1954)	(0.7984, 0.2341)	(0.8334, 0.1974)	(0.7770, 0.2575)	(0.9147, 0.0899)
S5	(0.7940, 0.2380)	(0.8657, 0.1499)	(0.8135, 0.2040)	(0.7830, 0.2475)	(0.7845, 0.2327)
LBR	(0.8578, 0.1544)	(0.8485, 0.1692)	(0.8461, 0.1681)	(0.8657, 0.1499)	(0.8503, 0.1644)
UBR	(0.9500, 0.0500)	(0.9500, 0.0500)	(0.9500, 0.0500)	(0.9500, 0.0500)	(0.9500, 0.0500)

Note: LBR – Lower Bound of the Reference; UBR – Upper Bound of the Reference.

Table 4. The distances of the options from the references

Distances from local references					
	C1	C2	C3	C4	C5
S1	0.0000	0.0937	0.0000	0.0567	0.1922
S2	0.3032	0.0000	0.1810	0.0531	0.1552
S3	0.0705	0.0052	0.1777	0.0000	0.1008
S4	0.0318	0.0575	0.0210	0.0981	0.0000
S5	0.0737	0.0000	0.0342	0.0901	0.0670

Similar calculations are performed to determine the weighting coefficients for all criteria. Accordingly, the most important criterion is C1. The importance order of the criteria, based on Table 2, was found to be C1>C3>C2>C4>C5.

The experts' linguistic evaluations of the options are given in Table D2 in the Appendix D. Table 3 presents the q-ROF decision matrix and the q-ROF reference values.

As an example, the linguistic evaluations made by experts for the first alternative "S1" with respect to C1 and the corresponding q-ROFNs are provided as follows, respectively:

$$\frac{\dfrac{S1 \text{ with respect to } C1}{E1, E2, E3, E4, E5, E6, E7, E8, E9}}{(ML, VH, MH, VH, VH, VH, VH, VH, VH)} = \frac{\dfrac{S1 \text{ with respect to } C1}{\left(\mu_{11}^{(k)}, \nu_{11}^{(k)}\right)}}{\left\langle \begin{matrix} (0.35, 0.65), (0.95, 0.05), (0.65, 0.35), (0.95, 0.05), (0.95, 0.05), \\ (0.95, 0.05), (0.95, 0.05), (0.95, 0.05)(0.95, 0.05) \end{matrix} \right\rangle}.$$

The aggregated $x_{ij=11}$ value is computed via Eq. (A9) as follows, where $k = 1, \ldots, 9$.

$$x_{ij=11} = (\mu_{11}, v_{11})_{m \times n};\ (j = 1, \ldots, 5, \quad i = 1,\ k = 1, \ldots, 7)$$

$$q - ROFWA_{x_{ij=11}} = (\mu_{11}, v_{11}) =$$

$$\left(\sqrt[q=3]{1 - \prod_{k=1}^{l=9} \left(1 - \left(\mu_{11}^{(k)} \right)^{q=3} \right)^{\lambda_k}}, \prod_{k=1}^{l=9} \left(\left(\nu_{11}^{(k)} \right)^{q=3} \right)^{\lambda_k} \right)$$

$$x_{11} = (\mu_{11}, v_{11}) =$$

$$\left(\begin{matrix} \sqrt[3]{\begin{matrix} 1 - [\left(1 - 0.35^3\right)^{0.1111} x \left(1 - 0.95^3\right)^{0.1111} x \left(1 - 0.65^3\right)^{0.1111} \\ x \left(1 - 0.95^3\right)^{0.1111} x \left(1 - 0.95^3\right)^{0.1111} x \left(1 - 0.95^3\right)^{0.1111} \\ x \left(1 - 0.95^3\right)^{0.1111} x \left(1 - 0.95^3\right)^{0.1111} x \left(1 - 0.95^3\right)^{0.1111}] \end{matrix}}, \\ 0.65^{0.1111} x 0.05^{0.1111} x 0.35^{0.1111} x 0.05^{0.1111} x 0.05^{0.1111} \\ x 0.05^{0.1111} x 0.05^{0.1111} x 0.05^{0.1111} x 0.05^{0.1111} \end{matrix} \right)$$

$$x_{11} = (\mu_{11}, v_{11}) = (0.9240, 0.0825).$$

The distances of the options from the references are given in Table 4.

As an example, the distances of the first alternative "S2" with respect to the reference value of C1 is computed as follows, where $x_{r_L 1} = \left(\mu_{r_L 1}, \nu_{r_L 1}\right) = (0.8578, 0.1544)$, $x_{r_U 1} = \left(\mu_{r_U 1}, \nu_{r_U 1}\right) = (0.9500, 0.0500)$, $\mathcal{S}(x_{21}) = 0.5391$, $\mathcal{S}\left(x_{r_L 1}\right) = 0.8138$, $\mathcal{S}\left(x_{r_U 1}\right) = 0.9286$, and $\mathcal{S}(x_{11}) < \mathcal{S}\left(x_{r_L 1}\right)$.

$$d_{11} = \frac{1}{2}\left(\left| 0.5658^3 - 0.8578^3 \right| + \left| 0.4687^3 - 0.1544^3 \right| \right) = 0.3032$$

Then we obtained the weighted distances for d_{11} as follows: 0.3032 × 0.2190 = 0.0664. Finally, the weighted overall distances of options are given in Table 5.

According to the results in Table 5, S4 ranks first. The full ranking of the options is S4>S5>S1>S3>S2.

Table 5. The distances of the options from the references

Weighted distances from local references							
	C1	C2	C3	C4	C5	φ_i	Ranking
S1	0.0000	0.0188	0.0000	0.0107	0.0359	0.0654	3
S2	0.0664	0.0000	0.0370	0.0100	0.0290	0.1425	5
S3	0.0154	0.0010	0.0364	0.0000	0.0188	0.0717	4
S4	0.0070	0.0115	0.0043	0.0185	0.0000	0.0413	1
S5	0.0161	0.0000	0.0070	0.0170	0.0125	0.0527	2

4.3. Validity of findings

This section will analyze tests of the validity and reliability of the study's findings, as well as the model's responses to changes in parameters. The approach of reducing each criterion's weight coefficient by 10% and adding it equally to the weight coefficients of the other criteria will be employed to examine the changes in the criteria's weight coefficients. As a result, a distinct scenario will be created for each procedure, and the weight coefficient of a criterion will be decreased by 10%, 20%, ..., and 100%, accordingly. As a result, 50 scenarios will be created for each of the five evaluation criteria. Table D3 in the Appendix D presents the criterion weight coefficients for the scenarios. The ranking results obtained are presented in Figure 2.

When the results in Figure 2 are examined, the most noticeable changes are observed in SN30, SN49, and SN50. Modifications to the weight coefficient of the C5 criterion have led to greater changes in the results than those of the remaining criteria. C5 seems to be the most influential criterion in solving the problem. On the other hand, the agreement between the ranking results across the scenarios was assessed using the Kendall W coefficient. The test result was W = 0.835, indicating a high level of agreement.

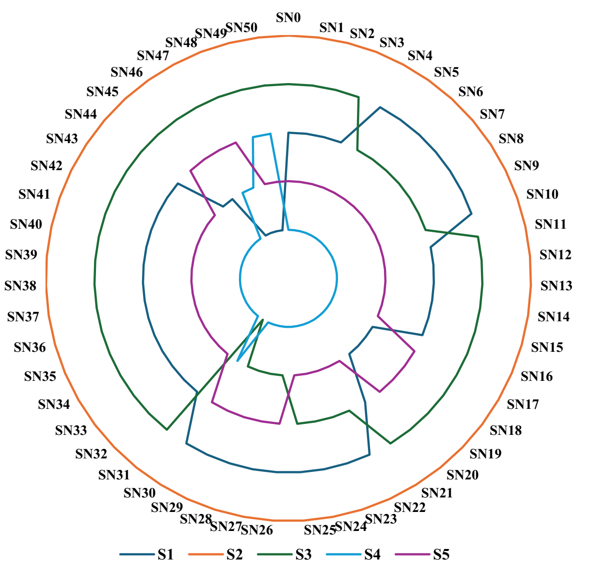

Figure 2. The results of the change in weight coefficients

The proposed methodology reflected the effects of the criterion weights on the solution of the problem. The rank reversal problem will be examined in the second phase. In this case, the problem's options will be removed one by one, and the relative order of the remaining options will be determined. The results are shown in Table 6.

Table 6. The results of the rank reversal problem examination

Excluded options				
	–	S2	S2, S3	S2, S3, S1
S1	3	3	3	–
S2	5	–	–	–
S3	4	4	–	–
S4	1	1	1	1
S5	2	2	2	2

The results in Table 6 show that q-ROF-REF does not cause rank reversal problems. In the final stage, the results obtained using known methods will be compared with those from the proposed methodology. In this context, the results obtained with q-ROF-ARAS, q-ROF-CoCoSo, q-ROF-CRADIS, q-ROF-RAFSI, q-ROF-SAW, q-ROF-TOPSIS, q-ROF-WASPAS, and q-ROF-WPM are presented in Table 7.

The agreement between results obtained using the different methods listed in Table 7 was examined using the Kendall W coefficient. This score (W = 0.98) represents a high level of agreement between the results obtained. Furthermore, it was observed that the ranking results from q-ROF-REF were highly correlated with those from other

Table 7. The results of the different methods

	q-ROF-REF	q-ROF-ARAS	q-ROF-CoCoSo	q-ROF-CRADIS	q-ROF-RAFSI	q-ROF-SAW	q-ROF-TOPSIS	q-ROF-WASPAS	q-ROF-WPM
S1	3	2	2	2	2	2	2	2	2
S2	5	5	5	5	5	5	5	5	5
S3	4	4	4	4	4	4	4	4	4
S4	1	1	1	1	1	1	1	1	1
S5	2	3	3	3	3	3	3	3	3

methods ($r_{Spearman}$ = 0.90). The examinations conducted in this section demonstrate the efficiency and validity of our approach. The proposed method can reflect parameter changes in the solution of the problem, does not cause changes in order, and produces results consistent with well-known methods.

5. Discussion

Our findings indicate that "*high initial costs-C1*" are the main barriers to GB construction project management. This aligns with the research by Ayarkwa et al. (2022), which identified them as challenges to the adoption of GB projects, emerging across different project phases. Further parameters that raise costs include an all-team design methodology, combining project teams, and appointed objectives (Chaisaard & Taemthong, 2018). To make this difficulty easier to handle, assistance from the administration is required. According to Orsi et al. (2020), the design of GBs is time-consuming, thereby increasing costs. Technologies, durable materials, and processes affect construction costs. While the costs of GBs are estimated to be only 1.8% higher than those of conventional buildings (Dwaikat & Ali, 2016), others report costs exceeding 6% (Hu & Skibniewski, 2021). To overcome the cost-related barrier, it is advisable for authorities to implement an integrated approach comprising strategic collaboration, local resource use, and policy support. Government incentives could motivate developers' investment in sustainable construction. Using locally available materials can considerably reduce the costs associated with importing green materials. Funds and resources for durable projects can be supplemented through collaboration between the government and the private sector. Operational expenses can be reduced over the long term through energy-efficient design approaches. "*Insufficient government incentives-C3*" is the second main barrier to these projects. This confirms the findings of Samari et al. (2013), which indicated that the absence of government incentives limits consultants and contractors' ability to implement GBs. Similar findings are reported by Love et al. (2012), who found that the implementation of green technologies is impeded by a lack of incentives. Additionally, AlSanad (2015), in exploring the impediments and enablers of green construction, found the absence of such incentives to be a crucial barrier.

The results obtained from our approach in the q-ROF environment indicated that the "financial incentives-S4" strategy is the most appropriate for handling GB construction projects. In the Kenyan case, endorsement efforts from executive bodies and industry associations should be leveraged to drive policy shifts, including grants and tax reductions for sustainable projects. Green construction can be promoted through technical expertise and financial backing from both public and private sectors. In addition, non-monetary incentives should be introduced by the governments. The financial implications can then be reduced by cooperative investment models and community-driven techniques.

6. Conclusions and future recommendations

Our study explores the critical barriers to GB construction projects and identifies the most important strategies to overcome them. For that purpose, a new integrated qROFS-PIPRECIA-REF approach is introduced, and the REF approach is extended within the qROFS environment for the first time in the literature. Our findings indicated that while "*high initial costs*" and "*insufficient government incentives*" are the main barriers to GB construction projects, financial incentives are the most appropriate strategies to overcome them. Although our study has contributed to the body of literature on GB construction projects in these areas of Kenya, some limitations are evident. First, the choice of criteria and alternatives did not follow a methodical literature review or a clear procedure. This limitation may introduce a degree of subjectivity in the selection process, as the identified criteria and alternatives could be influenced by the available literature and expert judgment rather than a fully systematic identification framework. Second, the study's findings cannot be applied to other African regions due to changes in local circumstances. This is because contextual differences such as regulatory environments, economic conditions, and stakeholder engagement practices may vary significantly across regions, thereby limiting the direct transferability of the results. Future studies should replicate this study framework using other countries within the East Africa region. Lastly, our study adopted the methodology under the q-ROF environment. Future research should consider integrating multiple fuzzy sets and evaluating alternative criteria for decision-making.

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APPENDIXES

Appendix A. The preliminaries of Q-Rung Orthopair fuzzy sets

A q-ROFS $\tilde{G}$ in a finite universe of discourse X is defined as $\tilde{G}=\left\{x,\left(\mu_{\tilde{G}}(x),\nu_{\tilde{G}}(x)\right)\middle| x\in X\right\}$, where $\mu_{\tilde{G}}(x):X\to[0,1]$ is the membership function, and $\nu_{\tilde{G}}(x):X\to[0,1]$ is the non-membership function. Where, the condition $0\le\left(\mu_{\tilde{G}}(x)^q+\nu_{\tilde{G}}(x)^q\right)\le 1,(q\ge 1)$ is met. The indeterminacy degree is defined as $\pi_{\tilde{G}}(x)=\sqrt[q]{1-\mu_{\tilde{G}}(x)^q-\nu_{\tilde{G}}(x)^q}$.

Assume that $g_1=\left(\mu_{g_1},\nu_{g_1}\right)$ and $g_2=\left(\mu_{g_2},\nu_{g_2}\right)$ be two q-ROF numbers (q-ROFNs). The basic operations, the score function, the accuracy function, and the Minkowski distance measure are defined in Eqs. (A1)–(A8), where $\lambda>0$, and $p\ge 1$:

$$g_1\otimes g_2=\left(\sqrt[q]{\mu_{g_1}^q+\mu_{g_2}^q-\mu_{g_1}^q\mu_{g_2}^q},\nu_{g_1}\nu_{g_2}\right); \quad (A1)$$

$$g_1\otimes g_2=\left(\mu_{g_1}\mu_{g_2},\sqrt[q]{\nu_{g_1}^q+\nu_{g_2}^q-\nu_{g_1}^q\nu_{g_2}^q}\right); \quad (A2)$$

$$\lambda g_1=\left(\sqrt[q]{1-\left(1-\mu_{g_1}^q\right)^{\lambda}},\nu_{g_1}^{\lambda}\right),\ \lambda\ge 0; \quad (A3)$$

$$g_1^{\lambda}=\left(\mu_{g_1}^{\lambda},\sqrt[q]{1-\left(1-\nu_{g_1}^q\right)^{\lambda}}\right),\ \lambda\ge 0; \quad (A4)$$

$$\left(g_1\right)^c=\left(\nu_{g_1},\mu_{g_1}\right); \quad (A5)$$

$$\mathcal{S}\left(g_1\right)=\frac{1}{2}\left(\mu_{g_1}^q-\nu_{g_1}^q+1\right),\ \mathcal{S}\left(g_1\right)\in[0,1]; \quad (A6)$$

$$\mathcal{A}\left(g_1\right)=\mu_{g_1}^q+\nu_{g_1}^q,\ \ \mathcal{A}\left(g_1\right)\in[0,1]; \quad (A7)$$

$$d_M\left(g_1,g_2\right)=\sqrt[p]{\frac{1}{2}\left(\left|\mu_{g_1}^q-\mu_{g_2}^q\right|^p+\left|\nu_{g_1}^q-\nu_{g_2}^q\right|^p\right)}. \quad (A8)$$

$d_M\left(g_1,g_2\right)$ is the Hamming distance between g_1 and g_2 when p = 1. On the other hand, $d_M\left(g_1,g_2\right)$ is the Euclidean distance between g_1 and g_2 when p = 2.

Let $g_j=\left(\mu_{g_j},\nu_{g_j}\right)$ be a collection of q-ROFNs, and $w=\left(w_1,\ldots,w_n\right)$ be a weight coefficient vector of g_j, where $j=1,\ldots,n$, $\sum_{j=1}^{n}w_j=1$, and $0\le w_j\le 1$. The q-ROF weighted average operator (q-ROFWAO) is defined in Eq. (A9).

$$q-ROFWAO_j=\left(\sqrt[q]{1-\prod_{j=1}^{n}\left(1-\mu_{g_j}^q\right)^{w_j}},\prod_{j=1}^{n}\nu_{g_j}^{w_j}\right). \quad (A9)$$

Appendix B. The qROFS- PIPRECIA- REF based methodology

The application steps of the methodology to be used to solve the problem are presented below.

***Step* 1**. The decision-making problem is structured in terms of experts $E=\left\{E_1,\ldots,E_k,\ldots E_l\right\}$, criteria $C=\left\{C_1,\ldots,C_j,\ldots C_n\right\}$, and options $O=\left\{O_1,\ldots,A_i,\ldots O_m\right\}$.

***Step* 2**. The weight coefficient of each expert is determined. In this context, the linguistic terms listed in Table B1 in Appendix is used. Accordingly, $l_k=\left(\mu_k,\nu_k\right)$ represents the importance of rating of k^{th} expert's evaluations. The weight coefficient of each expert is computed by applying Eq. (A10) (Aytekin et al., 2024).

$$\lambda_k=\frac{\frac{1}{2}\left(\left(\mu_k^q-\nu_k^q\right)+1\right)}{\sum_{k=1}^{l}\left[\frac{1}{2}\left(\left(\mu_k^q-\nu_k^q\right)+1\right)\right]}, \quad (A10)$$

where $0\le\lambda_k\le 1$ and $\sum_{k=1}^{l}\lambda_k=1$.

Table B1. The linguistic terms and their corresponding q-ROFNs

Linguistic terms	Linguistic terms	The corresponding q-ROFNs	
		μ	N
Very high	VH	0.95	0.05
High	H	0.80	0.20
Moderate high	MH	0.65	0.35
Moderate	M	0.5	0.5
Moderate low	ML	0.35	0.65
Low	L	0.20	0.80
Very low	VL	0.05	0.95

***Step* 3**. Experts evaluate the importance of criteria using the linguistic terms listed in Table B1. Accordingly, $\iota_j^{(k)}=\left(\mu_j^{(k)},\nu_j^{(k)}\right)$ denotes the q-ROF importance of j^{th} criterion determined by k^{th} expert.

***Step* 4**. The integrated q-ROF importance values $\iota_j=\left(\mu_j,\nu_j\right)$ are obtained using Eq. (A9).

***Step* 5**. The score function value of ι_j is computed via Eq. (A6). Thus, $\mathcal{S}\left(\iota_j\right)$ values are obtained.

***Step* 6**. c_j values are determined by comparing the criteria in pairs according to their order in the criteria list. For this purpose, Eq. (A11) is used, where $\mathcal{S}\left(\iota_j\right)$ and $\mathcal{S}\left(\iota_{j-1}\right)$ symbolize the importance ratings of the j^{th} criterion and $(j-1)^{\text{th}}$ criterion, respectively (Mishra et al., 2023).

$$c_j = \begin{cases} 1+\mathcal{S}(\iota_j)-\mathcal{S}(\iota_{j-1}), & if\ \mathcal{S}(\iota_j) > \mathcal{S}(\iota_{j-1}) \\ 1, & if\ \mathcal{S}(\iota_j) = S(\iota_{j-1}) \\ 1+\mathcal{S}(\iota_{j-1})-\mathcal{S}(\iota_j), & if\ \mathcal{S}(\iota_j) < \mathcal{S}(\iota_{j-1}) \end{cases}, \quad \text{(A11)}$$

where, c_j value of the criterion taken as the base for comparisons is assumed to be 1. For example, if comparisons are made using the C1 criterion as the base, then c_1 = 1.

***Step* 7**. The relative importance coefficient of each criterion is calculated by applying Eq. (A12).

$$\zeta_j = \begin{cases} 1, & if\ j=1 \\ 2-c_j, & if\ j>1 \end{cases}. \quad \text{(A12)}$$

***Step* 8**. The initial weight coefficient of each criterion is computed using Eq. (A13).

$$\vartheta_j = \begin{cases} 1, & if\ j=1 \\ \dfrac{\vartheta_{j-1}}{\zeta_j}, & if\ j>1 \end{cases}. \quad \text{(A13)}$$

***Step* 9**. The weight coefficient of each criterion is determined by applying Eq. (A14).

$$w_j = \frac{\vartheta_j}{\sum_{j=1}^{n}\vartheta_j}. \quad \text{(A14)}$$

Thus, the weight coefficients of criteria are determined using q-ROF-PIPRECIA. The following process steps are followed for the implementation of q-ROF-REF.

***Step* 10**. Experts evaluate the preferability/performance of options. Furthermore, experts determined the reference of each criterion. In all evaluation processes, the linguistic terms listed in Table B1 are used. Accordingly, $x_{ij}^{(k)} = \left(\mu_{ij}^{(k)}, \nu_{ij}^{(k)}\right)$ denotes the q-ROF ratings of i^{th} option in j^{th} criterion determined by k^{th} expert. Similarly, $x_{rj}^{(k)} = \left(\mu_{rj}^{(k)}, \nu_{rj}^{(k)}\right)$ is the q-ROF reference of j^{th} criterion determined by k^{th} expert. At this point, if the reference is determined as an interval, the lower bound is characterized by $x_{r_L j}^{(k)} = \left(\mu_{r_L j}^{(k)}, \nu_{r_L j}^{(k)}\right)$ and the upper bound is represented by $x_{r_L j}^{(k)} = \left(\mu_{r_U j}^{(k)}, \nu_{r_U j}^{(k)}\right)$. If there is a difference between experts in determining the reference as interval or point, the references determined as point are accepted as both the lower bound and the upper bound.

***Step* 11**. Experts' evaluations are integrated via Eq. (A9). As a result, the integrated q-ROF decision matrix $X = \left[x_{ij}\right]_{m\times n}$ is constructed, where $x_{ij} = \left(\mu_{ij}, \nu_{ij}\right)$. Similarly, the integrated references are determined as $x_{rj} = \left(\mu_{rj}, \nu_{rj}\right)$. In the evaluation process of experts in the previous step, if there is a reference determined in an interval by at least one expert in a criterion, the reference lower bound is integrated as $x_{r_L j} = \left(\mu_{r_L j}, \nu_{r_L j}\right)$ and the reference upper bound is integrated as $x_{r_U j} = \left(\mu_{r_U j}, \nu_{r_U j}\right)$.

***Step* 12**. The distance from the reference in criterion j is determined for each option. If the reference is in interval format, Eq. (A15) is used to compute the distance from the reference in criterion j for each option. On the other hand, if it is in point format, Eq. (A16) is employed.

$$d_{ij} = \begin{cases} \dfrac{1}{2}\left(\left|\mu_{ij}^q - \mu_{r_U j}^q\right| + \left|\nu_{ij}^q - \nu_{r_U j}^q\right|\right), & \mathcal{S}(x_{ij}) > \mathcal{S}(x_{r_U j}) \\ 0, & \mathcal{S}(x_{r_L j}) \le \mathcal{S}(x_{ij}) \le \mathcal{S}(x_{r_U j}) \\ \dfrac{1}{2}\left(\left|\mu_{ij}^q - \mu_{r_L j}^q\right| + \left|\nu_{ij}^q - \nu_{r_L j}^q\right|\right), & \mathcal{S}(x_{ij}) < \mathcal{S}(x_{r_L j}) \end{cases}; \quad \text{(A15)}$$

$$d_{ij} = \frac{1}{2}\left(\left|\mu_{ij}^q - \mu_{rj}^q\right| + \left|\nu_{ij}^q - \nu_{rj}^q\right|\right); \quad \text{(A16)}$$

where, $\mathcal{S}(x_{ij})$, $\mathcal{S}(x_{r_L j})$, and $\mathcal{S}(x_{r_U j})$ are the score function value equivalents of the q-ROFNs given in parentheses.

***Step* 13**. The weighted overall distance of each option is computed using Eq. (A17).

$$\varphi_i = \sum_{j=1}^{n} w_j d_{ij}. \quad \text{(A17)}$$

The option with the smallest φ_i value is ranked first. All options are sorted from smallest to largest according to their φ_i values.

Appendix C. Definition of criteria and alternatives

Table C1. Criteria and alternative definition

Criteria and alternatives	Description	References
High initial costs (C1)	This originated from sustainable products, labor with skills, and costly green materials	Otundo Richard (2024)
Lack of awareness (C2)	This has an impact on the insights and challenges associated with the GB projects	Expert opinion
Insufficient government incentives (C3)	This impedes the GB projects	Saka et al. (2021)
Technical challenges (C4)	This is due to the absence of training programmes	Tran (2020)
Regulatory barriers (C5)	This discourages the adoption of GB standards	Expert opinion
Stakeholder collaboration (S1)	This will allow them to work together in handling barriers and enhance SD	Expert opinion
Conducting public awareness campaigns (S2)	This increase acceptance of GBs, which drives the demand of market	Expert opinion
Implementing technical training programs (S3)	This gives individuals the necessary skills and ideas for durable construction	Otundo Richard (2024)
Financial incentives (S4)	This promotes compliance with GB regulations and soften upfront costs	
Streamlining regulatory processes (S5)	This shapes the GB practices adoption	

Table C2. Background information of the experts (Es)

Experts	Profession	Title	Education degree	Major	Experience (years)
E1	Architect	Principal architect	M.Sc.	Architecture	10
E2	Quantity surveyor	Quantity surveyor	B.Sc.	Building economics	10
E3	Quantity surveyor	Senior quantity surveyor	B.Sc.	Building economics	26
E4	Town planner	Senior town planner	B.Sc.	Urban and regional planner	15
E5	Marketing	Ag. sales & marketing manager	B.Sc.	Business administration	15
E6	Civil and structural engineering	Lecturer	Ph.D.	Environmental engineering	23
E7	Civil and structural engineering	Lecturer	B.Sc.	Civil engineering	11
E8	Engineer	Lecturer	Ph.D.	Civil engineering	9
E9	Civil engineer	Lecturer	M.Sc.	Civil engineering	5

Appendix D. Experts' evaluation related to criteria and alternatives

Table D1. Evaluations of experts regarding the importance of criteria

Experts	C1	C2	C3	C4	C5
E1	M	MH	MH	M	M
E2	H	VH	H	ML	M
E3	VH	ML	H	MH	ML
E4	VH	M	M	VH	VH
E5	H	VH	VH	H	VH
E6	H	VH	VH	MH	M
E7	VH	H	VH	MH	MH
E8	VH	MH	M	H	ML
E9	VH	ML	MH	H	MH

Table D2. Evaluations of options provided by experts

	Options	C1	C2	C3	C4	C5		Options	C1	C2	C3	C4	C5		Options	C1	C2	C3	C4	C5
E1	S1	ML	M	MH	ML	M	E4	S1	VH	VH	VH	VH	H	E7	S1	VH	VH	VH	VH	VH
	S2	L	ML	M	M	ML		S2	MH	VH	MH	VH	H		S2	MH	H	H	VH	H
	S3	MH	MH	ML	L	ML		S3	VH	VH	VH	VH	VH		S3	VH	VH	MH	VH	MH
	S4	M	M	ML	MH	MH		S4	VH	VH	VH	VH	MH		S4	VH	VH	VH	MH	VH
	S5	MH	M	M	ML	M		S5	VH	H	VH	VH	H		S5	H	VH	VH	H	H
	LBR	H	M	VH	MH	M		LBR	M	VH	M	VH	VH		LBR	VH	H	VH	H	H
	UBR	VH	VH	VH	VH	VH		UBR	VH	VH	VH	VH	VH		UBR	VH	VH	VH	VH	VH
E2	S1	VH	ML	VH	M	VL	E5	S1	VH	M	VH	M	M	E8	S1	VH	MH	M	H	ML
	S2	MH	M	H	M	ML		S2	MH	VH	M	H	H		S2	ML	VH	MH	L	H
	S3	M	H	VL	H	M		S3	M	H	M	VH	VH		S3	ML	H	MH	VH	L
	S4	H	H	H	ML	VH		S4	MH	M	VH	H	VH		S4	VL	ML	L	M	VH
	S5	H	M	MH	M	H		S5	M	VH	H	MH	VH		S5	L	VH	H	MH	M
	LBR	H	VH	H	M	MH		LBR	H	H	MH	M	VH		LBR	M	ML	MH	VH	H
	UBR	VH	VH	VH	VH	VH		UBR	VH	VH	VH	VH	VH		UBR	VH	VH	VH	VH	VH
E3	S1	MH	M	VH	M	M	E6	S1	VH	H	H	VH	MH	E9	S1	VH	ML	H	M	ML
	S2	L	H	MH	M	M		S2	MH	H	MH	VH	H		S2	M	VH	M	MH	ML
	S3	L	H	MH	H	M		S3	VH	MH	MH	VH	H		S3	M	H	M	VH	M
	S4	M	H	M	M	H		S4	VH	H	H	VH	VH		S4	H	ML	MH	M	VH
	S5	M	MH	M	M	M		S5	VH	VH	MH	VH	H		S5	MH	MH	H	MH	H
	LBR	H	MH	VH	MH	M		LBR	VH	H	MH	VH	H		LBR	VH	VH	H	VH	VH
	UBR	VH	VH	VH	VH	VH		UBR	VH	VH	VH	VH	VH		UBR	VH	VH	VH	VH	VH

Table D3. The scenarios regarding the weight coefficient change

	C1	C2	C3	C4	C5
SN0	0.2190	0.2007	0.2047	0.1888	0.1868
SN1	0.1971	0.2062	0.2101	0.1943	0.1923
SN2	0.1752	0.2116	0.2156	0.1997	0.1978
SN3	0.1533	0.2171	0.2211	0.2052	0.2032
SN4	0.1314	0.2226	0.2266	0.2107	0.2087
SN5	0.1095	0.2281	0.2321	0.2162	0.2142
SN6	0.0876	0.2335	0.2375	0.2216	0.2197
SN7	0.0657	0.2390	0.2430	0.2271	0.2251
SN8	0.0438	0.2445	0.2485	0.2326	0.2306
SN9	0.0219	0.2500	0.2540	0.2381	0.2361
SN10	0.0000	0.2554	0.2594	0.2435	0.2416
SN11	0.2241	0.1806	0.2097	0.1938	0.1918
SN12	0.2291	0.1605	0.2147	0.1988	0.1968
SN13	0.2341	0.1405	0.2197	0.2038	0.2019
SN14	0.2391	0.1204	0.2247	0.2089	0.2069
SN15	0.2441	0.1003	0.2298	0.2139	0.2119
SN16	0.2491	0.0803	0.2348	0.2189	0.2169
SN17	0.2542	0.0602	0.2398	0.2239	0.2219
SN18	0.2592	0.0401	0.2448	0.2289	0.2270
SN19	0.2642	0.0201	0.2498	0.2339	0.2320
SN20	0.2692	0.0000	0.2548	0.2390	0.2370
SN21	0.2242	0.2058	0.1842	0.1939	0.1919
SN22	0.2293	0.2109	0.1637	0.1990	0.1970
SN23	0.2344	0.2160	0.1433	0.2041	0.2022
SN24	0.2395	0.2212	0.1228	0.2092	0.2073
SN25	0.2446	0.2263	0.1023	0.2144	0.2124
SN26	0.2497	0.2314	0.0819	0.2195	0.2175
SN27	0.2549	0.2365	0.0614	0.2246	0.2226
SN28	0.2600	0.2416	0.0409	0.2297	0.2277
SN29	0.2651	0.2467	0.0205	0.2348	0.2329
SN30	0.2702	0.2519	0.0000	0.2399	0.2380
SN31	0.2238	0.2054	0.2094	0.1699	0.1915
SN32	0.2285	0.2101	0.2141	0.1510	0.1963
SN33	0.2332	0.2148	0.2188	0.1321	0.2010
SN34	0.2379	0.2196	0.2235	0.1133	0.2057
SN35	0.2426	0.2243	0.2283	0.0944	0.2104
SN36	0.2474	0.2290	0.2330	0.0755	0.2151
SN37	0.2521	0.2337	0.2377	0.0566	0.2199
SN38	0.2568	0.2384	0.2424	0.0378	0.2246
SN39	0.2615	0.2432	0.2471	0.0189	0.2293
SN40	0.2662	0.2479	0.2519	0.0000	0.2340
SN41	0.2237	0.2054	0.2093	0.1935	0.1681
SN42	0.2284	0.2100	0.2140	0.1981	0.1495
SN43	0.2331	0.2147	0.2187	0.2028	0.1308
SN44	0.2377	0.2194	0.2234	0.2075	0.1121
SN45	0.2424	0.2240	0.2280	0.2121	0.0934
SN46	0.2471	0.2287	0.2327	0.2168	0.0747
SN47	0.2517	0.2334	0.2374	0.2215	0.0560
SN48	0.2564	0.2380	0.2420	0.2261	0.0374
SN49	0.2611	0.2427	0.2467	0.2308	0.0187
SN50	0.2658	0.2474	0.2514	0.2355	0.0000