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Grey preferences selection index with trimmed group preference for evaluating university dormitory renovation design

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Renovating old buildings is a strategic approach to resource optimization and sustainability. However, dormitory design decisions are often made by a limited panel of experts, which risks excluding student preferences-key to the design process. Expert assumptions about student needs can lead to biased outcomes, and attempts to gather student input may suffer from respondent bias and inconsistent engagement, introducing data noise. This paper presents the Grey Trimmed Preferences Selection Index (GTPSI) Multi-Criteria Decision Making (MCDM) method, an improved preference selection index MCDM method that integrates expert weights and refines student feedback by filtering outliers, using interval grey numbers to address uncertainty. Applied to dormitory renovation proposals, GTPSI provides a stable ranking framework, as confirmed by whitening sensitivity analysis, ensuring consistency across grey bounds. To further validate the selected alternative, results are cross-verified with TOPSIS and ELECTRE-III, reinforcing GTPSI's robustness in aligning renovation designs with actual student needs. The GTPSI method thus offers a comprehensive solution for integrating user-centered preferences into expert evaluations, promoting designs that better meet stakeholder expectations.

As of the second half of the year 2023, China boasted over 3072 tertiary institutions, many of which were established before 1990. This indicates a significant number of these institutions have infrastructure that is a prime candidate for overhaul. According to Wang et al.[1], the average lifespan of a building in China is 34 years, suggesting that while demolishing and retrofitting could extend a building's lifespan, renovation is a maintenance exercise that imbues old structures with a sense of newness for their users. From 1990 to 2024, which is 34 years, many university structures are due for demolishing, renovation, or retrofitting. By adopting sustainable design principles, institutions can not only reduce their carbon footprint and conserve natural resources but also create products that are more energy-efficient and cost-effective. Furthermore, sustainable design improves the quality of life for people and communities by promoting healthier living environments and reducing exposure to harmful chemicals and pollutants[2].

Efforts to provide students, who are the future of tomorrow, with the best available living conditions represent the overarching goal of university authorities, both through government and private ownership of these institutions[3]. However, relying solely on experts in the decision-making process creates an imbalance, neglecting the perspectives of the actual users of these facilities. Notably, incorporating student input in the design of their dormitories can significantly enhance the effectiveness and satisfaction of their campus life experience[4]. This includes increasing students' desire to contribute to the community and having a positive impact on their mental health[5]; increased engagement and ownership of their living spaces promote a sense of responsibility and foster a positive living culture that can adapt to their learning needs. A challenge arises in incorporating suggestions from many students into the design process. This paper addresses the selection and evaluation of various student designs as a multi-criteria decision-making (MCDM) problem, highlighting the complexity and importance of including diverse student perspectives in creating effective living environments[6].

A multi-criteria decision-making (MCDM) problem involves selecting from among alternatives that are evaluated based on various, often conflicting, criteria, with each alternative's performance assessed against each criterion. In the evaluation process, weights are assigned to reflect the relative importance of each criterion.

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Standard techniques for addressing MCDM problems include the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)[7], Analytic Hierarchy Process (AHP)[6], and the Elimination and Choice Expressing Reality (ELECTRE) method, among others[8]. Weights can be categorized into two types: objective, which are determined by mathematical models or quantitative data, and subjective, which are based on the judgment and preferences of decision-makers (DMs). To enhance the accuracy of the weighting process, the judgments of multiple DMs can be integrated, an approach known as group decision-making. While group decision-making has its benefits, it also introduces uncertainty. This paper employs grey system theory to manage the uncertainty inherent in group decision-making environments[9].

Deng proposed the grey system theory[10] and has since been further developed by Liu[11] along with scholars worldwide. Conceptually, a grey system exists between a white system and a black system. By definition, a black system is one with completely unknown information, while a white system is characterized by fully known information. Therefore, deductively, a grey system is one with incomplete information and is thus referred to by the term "grey." There are various types of grey numbers, including those with only lower bounds and those with only upper bounds. Specifically, interval grey numbers are utilized in this research, meaning grey numbers with lower and upper bounds. It is essential to distinguish that an interval grey number differs from an interval number. While an interval number represents a continuous range from the lower to the upper bounds, an interval grey number refers to an unknown number within a known range, i.e., between the lower and upper bounds.

In universities, using points in tens and hundreds is a common practice for student assessment. Consequently, the point allocation method extended to the grey system theory (GST), is utilized for weighting in the context of MCDM. The Preference Selection Index (PSI) MCDM method developed by Maniya et al.[12] was first applied in material selection problem that is still relevant today. MCDM evaluation methods can be categorized into compensatory and non-compensatory approaches, with the classical PSI falling into the compensatory category. While large-scale group decision-making in MCDM presents several advantages, such as a diversity of perspectives and broader stakeholder involvement, it also introduces challenges[13]. When comparing the GTPSI method to existing MCDM, their are some significant differences. Some of the existing MCDM methods do not account for uncertainty, some existing method are not designed for group decision-making, and even the few capable of group decision-making are not robust for large group of decision makers (DMs), specifically DMs in the hundreds. Proper management of of large group decison-making process is crucial to leverage its benefits while minimizing the drawbacks, such as noise, by refining the data. The GTPSI addressess these shortcoming i.e. been able to capture uncertainty for large group decision-making problem.

In essence, this paper makes three principal improvements to the PSI initially developed by Maniya[12]. First, it refines the PSI by integrating subjective weights within a group decision-making context. Second, it expands the PSI to accommodate large-group preference decision-making, analyzing over a hundred sample variables to establish the performance value of alternatives. Third, it addresses the inherent uncertainty in group decision-making and large-group scenarios using the GST. An additional contribution of this paper is the introduction of a hierarchical model suited for renovation projects in the construction industry. The remainder of this paper is structured as follows: Sect. "Literature review" in provides a review of literature related to projects and PSI research. Section "Methodology" in outlines the methods and steps for the GTPSI approach. Section "Result and analysis" in presents the research findings and their analysis. Section "Conclusion" in concludes the paper.

Literature review

The application of PSI (Preference Selection Index) in addressing Multi-Criteria Decision Making (MCDM) problems within sustainable construction and renovation design is a focal point of this review, underscoring the method's significance in enhancing decision-making processes. As sustainability becomes increasingly crucial in construction practices, the emphasis shifts towards methods that can effectively reduce buildings' environmental impacts while simultaneously improving efficiency and comfort for occupants. While the grey relational analysis is commonly applied in traditional Grey MCDM[14], this literature review aims to highlight the evolving landscape of sustainable construction and renovation design, acknowledging the pivotal role of research and practice in steering the industry towards more environmentally friendly and efficient solutions.

Sustainable renovation and construction design

Sustainable renovation and construction design have rapidly evolved into pivotal areas of focus within research and practice, dedicated to diminishing the environmental footprint of buildings while simultaneously elevating their efficiency and the comfort of their occupants. Central to this approach is the integration of environmental considerations into construction and renovation projects, aiming to minimize resource use and environmental degradation. The World Green Building Council outlines essential guidelines for environment-friendly planning and development, highlighting the role of sustainable design in mitigating climate change impacts[15].

The importance of renovation projects in enhancing building sustainability is well-documented. In particular, Pombo, et al.[16] critically review housing retrofit strategies, advocating for a life cycle approach to identify optimal sustainable renovation solutions. This perspective is supported by Pope et al.[17], who developed a decision tool to assist stakeholders in choosing between renovation and new construction, emphasizing the potential of renovation in achieving sustainability targets. Iwaro and Mwasha[18] examined the role of sustainable development concept in sustainable envelope design through the impacts of sustainable envelope design on building sustainability based on Integrated Performance Model.

The impact of sustainable renovation on reducing energy consumption is well-documented. Alwisy et-al.[19] advance green building practices by ranking design factors critical for achieving sustainability in construction, highlighting the role of systematic criteria-based evaluations. Andersen et al.[20] explore the use of digitized building data to assess renovation potentials, underscoring the importance of data in informing sustainable renovation decisions. Despite notable advancements in sustainable renovation and construction design, challenges persist. The development of decision support systems, as proposed by Juan et al.[21], indicates the growing importance of technology in facilitating sustainable design decisions.

In the context of sustainable building practices, Ulutaş[22] investigation into natural fibre insulation via an integrated MCDM model underscores the significance of PSI in navigating the multifaceted criteria of energy conservation and environmental impact. This research contributes a hybrid MCDM methodology, enhancing the repertoire of tools available for advancing energy efficiency in construction.

PSI with MCDM application

The advent of Multi-Criteria Decision Making (MCDM) methods has revolutionized decision analysis by accommodating multiple conflicting criteria, a common scenario in various fields. Among these, the weighting MCDM methods and, more specifically, the application of the PSI have emerged as pivotal tools for decision-makers. The significance of PSI is underscored in studies across diverse domains, from optimizing manufacturing processes to environmental management, showcasing its versatility and effectiveness in complex decision scenarios.

Attri and Grover's[23] investigation into the PSI method during the design stage of the production system life cycle addresses the inherent complexity of strategic decision-making. By showcasing the method's accuracy and applicability through various case studies, their research validates PSI's potential as an efficient tool in navigating the intricate landscape of production design. This not only enriches the MCDM literature but also offers practical insights into enhancing decision-making processes in industrial settings. Similarly, Towaiq et al.'s[24] exploration of PSI in the Fused Deposition Modeling (FDM) printing process demonstrates the method's capability to systematically rank printing parameters. This application not only highlights PSI's practical utility in enhancing printing performance but also its role in tailoring solutions to meet specific mechanical qualities, mass, and duration requirements. Such findings contribute significantly to the ongoing discourse on the optimization of manufacturing processes, presenting PSI as a robust tool for decision-making in engineering applications.

In the realm of manufacturing, Madić et al.'s[25] study on optimizing $\mathrm{CO_2}$ laser cutting of stainless steel further evidences the PSI method's applicability. The simplicity and directness of PSI, as highlighted in their findings, underscore its suitability for manufacturing environments where decisions need to be made swiftly and effectively. However, the study also brings to light the limitations of PSI in scenarios with closely aligned attribute values, enriching the dialogue on the method's applicability and scope. Furthermore, the application of PSI in the optimization of wear parameters in Kumar et al.[26] study on $\mathrm{Cr_2\,O_3}$/TiAlN ceramic coatings introduces a comprehensive approach to material science challenges. Their methodology, employing a fuzzy integrated PSI-Combinative Distance-based Assessment (CODAS) method, not only advances the understanding of wear characteristics but also exemplifies the PSI method's effectiveness in ranking and optimizing experimental conditions, providing a blueprint for future research in material optimization.

Furthermore, Pathak et al.[27] exemplify the integration of PSI with metaheuristic methods to refine scanning process parameters. Their research, employing a Taguchi $\mathrm{L_{27}}$ orthogonal array and an analytical model, underscores PSI's efficacy in eschewing the need for weighting criteria, thus streamlining decision-making processes. In the automated manufacturing sector, Maniya and Bhatt[12] was the first develop and advocate for PSI's simplicity and logic in facilitating the selection of Flexible Manufacturing Systems (FMS). Their analysis through distinct FMS selection problems affirms PSI's capacity to navigate qualitative criteria, suggesting a broader applicability in simplifying complex decision matrices in manufacturing settings.

Extending the utility of PSI beyond manufacturing, Barman et al.'s study in the geographical terrains of Aizawl, Mizoram, India, leverages PSI for groundwater mapping. By integrating PSI with the Inverse Distance Weighting (IDW) technique, they address the nuanced challenge of precipitation washout, categorizing groundwater potential zones with remarkable granularity. This application vividly illustrates PSI's adaptability, offering a pragmatic approach for environmental management and resource conservation.

Moreover, the studies by Trung[28], and Gligorić et al.[29], respectively, reveal the broad applicability and effectiveness of PSI in optimizing turning operations for manufacturing and selecting support systems in mining. Duc Trung's identification of optimal conditions for minimal surface roughness and maximal material removal rate, alongside Gligorić et al.'s hybrid model combining Modified PSI and Magnitude of the Area for the Ranking of Alternatives (MARA) methods, showcases PSI's versatility in addressing diverse MCDM problems across industrial operations and engineering challenges.

The role of PSI extends beyond manufacturing into environmental management, as demonstrated by Demir and Moslem[30]. Their development of a multi-criteria decision-making framework, incorporating the Fuzzy-PSI for medical waste disposal during the COVID-19 pandemic, underscores the method's adaptability and importance in crisis situations. This research not only provides a novel approach to managing medical waste but also introduces a model that could be replicated in similar emergency scenarios, emphasizing the flexibility and utility of PSI in addressing unforeseen challenges.

Pamucar et al.'s[31] fuzzy group MCDM approach, integrating PSI with other methods for green supplier selection, highlights the method's adaptability and potential for innovation. By developing a framework that enhances the efficiency and reliability of the supplier selection process, this study not only contributes to the sustainability discourse but also showcases the PSI method's capacity for integration with other decision-making tools, offering a multifaceted approach to complex problems.

Uncertainty in MCDM can arise from various sources, including incomplete information, imprecise data, and subjective judgments. Table 1 summarizes some selected research that used PSI in the literature. The field of MCDM is constantly evolving, with new methodologies and applications emerging to tackle the complexities inherent in contemporary decision-making scenarios. The integration of GST into MCDM marks a significant advancement, providing enhanced capabilities for managing data uncertainty and improving the accuracy of decisions. Upon reviewing the existing literature, we believe this paper is among first to address the gap

Authors	Weighting methods	Evaluation methods	Uncertainty methods	Applications
Attri & Grover[23]	PSI	PSI	Non	Production system design
Demir & Moslem[30]	Fuzzy PSI	Fuzzy COSDIS	Fuzzy set	Medical waste disposal during COVID-19 in in Sivas, Turkey.
Duc Trung[28]	PSI	PEG, PSI, CURLI	Non	Turning operation in manufacturing
Gligoric et al.[29]	PSI	MARA	Non	Support system selection in underground mining
Kumar et al.[26]		PSI-CODAS	Fuzzy set	Ceramic coating wear parameter optimization
Pamucar et al.[31]		CoCoSo, PSI	Fermatean fuzzy set	Green supplier selection in textile industry
Pathak et al.[27]	PSI	PSI with Taguchi L_{27}	Non	Optimization of 3D scanning process conditions
Towaiq et al.[24]	PSI	PSI	Non	FDM 3D printing process parameters selection
Ulutas[22]	LOPCOW	MEREC, MCRAT, PSI	Non	Evaluation of natural fibre insulating materials for construction insulation

Table 1. Selected study of the use of PSI.

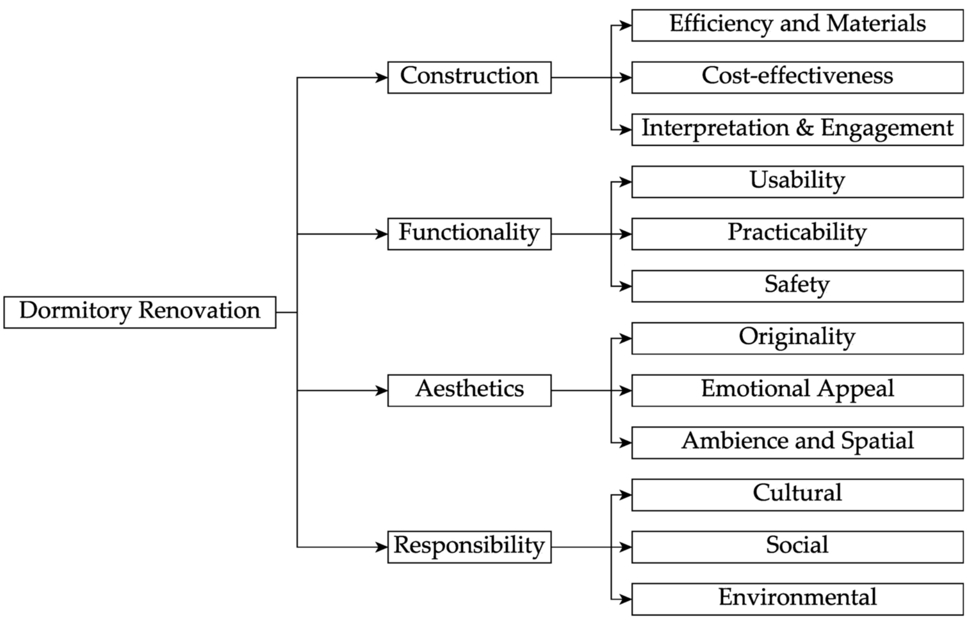

Fig. 1. Hierarchical model.

concerning the weighting limitation with the PSI. More importantly, this work pioneers the extension of PSI to accommodate group preferences and group decision-making under uncertainty, leveraging the GST.

Methodology
Evaluation criteria
The criteria for evaluating dormitory renovation design is presented is a hierarchical model in Fig. 1. This model outlines a structured decision-making framework that categorizes the different aspects of renovation into four primary criteria: Construction, Functionality, Aesthetics, and Responsibility. Each of these primary criteria is further divided into sub-criteria that detail specific areas of consideration as explained below:

Construction
Construction (C_1) is among the critical criteria in the renovation that is responsible for the approach of integrating efficient and renewable energy sources, ecologically friendly materials, and economic principles throughout the life cycle of completing this round of renovation[32,33] *Efficiency and Materials* (C_{1-1}) This consists of the approach of using technology in construction that contributes to sustainability, For example, the use do modular prefabrication panels[34], and the use of energy efficiency practices[35], that are synergistic in design. considering decarbonization[36] as well as life cycle perspective[37] *Cost-effectiveness* (C_2) measures the strategic use of funds to achieve high energy efficiency and sustainability under budget constraints.[38] (C_{1-2}) *Interpretation and Engagement* (C_{1-3}) are the stakeholder interpenetration of the design. The students' engagement knows that the dormitory is designed to promote sustainability, thus promoting equity and learning for sustainability based on the design-led participation as a strategic advantage for all[39–41].

Functionality
Functionality (C_2) measures the overall goal for renovation,i.e. integrating sustainability, as well as the existed to which the building serves the purpose it was erected, i.e. to provide accommodation for the student on campus while they are in pursuit of their education. The framework for resident build should be considered *Usability* (C_{2-1})[42]

Practicability (C_{2-2}) Efficient solutions in conducting the project that is not limited to Business Information Modeling (BIM), life cycle thinking and student focus renovation In other words, integrating practical and efficient solutions in the renovation the dormitory[43]. *Safety* C_{2-3}.Regardless of the approach for renovation, safe of construction workers and students cannnot be compromised in pursuit of saving the planet. This includes the structural integrity of the building and additional weight that it may bear, as well as the overall life cycle of the building[44], Employing technologies for safer buildings should be considered[45].

Aesthetics
Aesthetics (C_3) measures the overall appearance and appeal of the dormitory, such as the balance of colour and symmetry that are pleasing to the eyes. *Originality* (C_{3-1}) assess the uniqueness and innovativeness of the design that promotes visual appeal without compromising the environmental and economic payback[46]. While it is not uncommon for students to share ideas, the aesthetics should be inferred in the design[47]. *Emotional Appeal* (C_{3-2}) focus of providing an emotional connection between the students and their dormitory as part of their learning experience, maintaining their well-being and satisfaction which and spread a clear message about sustainability in years to come as aluminas[48,49]. *Ambience and Spatial* (C_{3-3}) aesthetics should not compromised the luminescence for reading and spontaneous studying[50]. While colours can change the mode of various environments, white is satisfactory[51]. Although the interior design is not captured in the contest, students have the option to provide scores based on their perceived position of interior design from the rendered renovation image.

Responsibility
Responsibility (C_4) measures the impact of incorporating cultural, social, and environmental values to maintain the heritage and position of the university. *Cultural* (C_{4-1}) responsibility is deeply rooted in the Chinese civilization, the harmony between the old and new; East and West; Ying and Yang assessed if balance is maintained. This approach ensures that renovation projects not only meet environmental and economic sustainability goals but also preserve and enhance cultural heritage[45,52,53]. *Social* (C_{4-2}) is the consideration of societal impacts and benefits, ensuring that renovation practices contribute positively to the community and environment. This criteria emphasizes the importance of sustainable practices that respect and support the well-being of individuals and communities. For example, the life cycle environmental and economic assessments[54] and design contributions to building technology[55]. *Environmental* (C_{4-3}) is reducing environmental impacts while enhancing energy efficiency and resource conservation. This criterion emphasizes the need for sustainable practices that are mindful of ecological balance and the long-term health of the environment[56,57].

Weighting methods
The grey point-allocation approach is used in the research, which is achieved by representing the decision-maker (DMs) preferences using interval grey numbers. The points are assigned to a are within a range that is easily understood. Commonly, in tens or hundreds. A point for 0–100 is used because the percentage is used in grading in the educational institution.

Step 1. Obtain the point for the criteria. The DMs score the criteria based on importance in percentage (0–100%).
Step 2. Represent obtained weight in grey numbers. The scores provided by the Group DMs are converted to interval grey numbers by taking the lower and highest points for each criterion.

I. First-level criteria: The percentage scores of the DMs L' in interval grey numbers with *u* first-level criteria is obtained using Eq. (1).

$$\otimes L' = \otimes l_1, \otimes l_2, \ldots, \otimes l_s, \tag{1}$$

where *s* is the last first-level criterion and $\otimes l_u = \left[\underline{l}_u, \bar{l}_u\right]$. The lower and upper bound of the DMs ratings are $\underline{l}_u = \min_{1 \le i \le m} (DM_i(L_u))$ and $\bar{l}_u = \max_{1 \le i \le m} (DM_i(L_u))$. respectively.

II. Second-level criteria: The percentage scores of the DMs L'' in interval grey numbers with *v* second-level criteria is obtained using Eq. (2).

$$\otimes L'' = \otimes l_{u-1}, \otimes l_{u-2}, \ldots, \otimes l_{u-t} \tag{2}$$

where *t* is the last first-level criterion and $\otimes l_u = \left[\underline{l}_{u-v}, \bar{l}_{u-v}\right]$. The lower and upper bound of the DMs ratings are $\underline{l}_{u-v} = \min_{1 \le i \le m} (DM_i(L_{u-v}))$ and $\bar{l}_{u-v} = \max_{1 \le i \le m} (DM_i(L_{u-v}))$, respectively.

Step 3. Obtain the Kernel of the interval grey number. This is a whitening process to convert the grey number to a real number using Eq. (3).

$$H = \underline{l}(1-\omega) + \bar{l}\omega \tag{3}$$

where ω is the whitening coefficient.

Step 4. Compute the criteria local weights. The white scores are scaled to unity then their root or top level hierarchy. This is computed as follows:

I. First-level criteria use Eq. 4:

$$c_u^{'}(h) = \frac{c_u(h)}{\sum_{u=1}^{\rho} c_u(h)}. \tag{4}$$

where *c* is the criterion with an index of *u*, and ρ is the index for the last first-level criterion.

II. Second-level criteria use Eq. (5) is used:

$$c_{u-v}^{'}(h) = \frac{c_{u-v}(h)}{\sum_{v=1}^{\sigma} c_{u-v}(h)}. \tag{5}$$

$\therefore \sum_{u=1}^{\rho} c_u^{'}(h) = 1$ and $\sum_{v=1}^{\sigma} c_{u-v}^{'}(h) = 1$. where *c* is the criterion with an index of *h*, and σ is the index for the last second-level criterion.

Step 5. Calculate the effective weights. This is multiplying the first- and second-level criteria weights as given in Eq. 6:

$$w_j^{'}(h) = c_u^{'}(h) \times c_{u-v}^{'}(h). \tag{6}$$

$\therefore \sum_{j=1}^{m} w_j^{'}(h) = 1.$

Evaluation methods

Preference selection index

Step 1. Goal identification: The determine the objective of the MCDM problem.

Step 2. Decision matrix formulation: Converting a decision table to a matrix for matrix operations. For a set of alternatives $A = A_i \text{ for } i = 1, 2, 3, \ldots, n$ and a set of decision criteria $C = C_j \text{for} j = 1, 2, 3, \ldots, m$, x_{ij} is the performance value of alternative A_i considering criteria C_j.

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1j} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix} \tag{7}$$

Step 3. Data normalization: This is making the data a common scale for direct comparison of alternatives across all criteria. A normalized matrix *R*, has element r_{ij} given in Eq. (8). For beneficial criteria ($j \in \mathcal{B}$), where higher performance values are better, and for cost criteria ($j \in \mathcal{H}$), where lower performance values are better.

$$r_{ij} = \begin{cases} \frac{x_{ij}}{x_j^{\max}} & \text{if} \quad j \in \mathcal{B} \\ \frac{x_j^{\min}}{x_{ij}} & \text{if} \quad j \in \mathcal{H} \end{cases} \tag{8}$$

Step 4. Preference variation value (Ψ_j) computation: This is similar to sample variance as given in Eq. (9).

$$PV_j = \sum_{i=1}^{N} \left[R_{ij} - \bar{R}_j\right]^2 \tag{9}$$

Step 5. Overall preference value computation: This is an objective weight that is obtained by computing the deviation from preference value, (*PV*) as giving in Eq. (10)

$$\Psi = \frac{\Phi_j}{\sum_{j=1}^{M} \Phi} \tag{10}$$

where $\Phi_j = 1 - PV_j$ and $\sum_j \Psi = 1$.

Step 6. Preference Selection Index (PSI) computation: Here PSI (I_i),

$$I_i = \sum_{j=1}^{M} (R_{ij} \times \Psi_j) \tag{11}$$

Step 7. Alternative ranking: The PSI is ranked, alternative with this highest PSI (I_i) is the best.

Grey trimmed preference selection index

The main concept of the GTPSI (Grey Target Performance Suitability Index) is to represent the performance values of alternatives A_i using grey numbers when multiple performance values are obtained for the same criterion and alternative. In large group decision-making problems, noise is often introduced, and accounting for the entire range, including outliers, may become less meaningful. For instance, when the minimum and maximum values are represented in a grey interval number, and no additional information is provided, this becomes a "black" number, meaning it conveys no useful information. A more concrete example can be observed in the case of an interval grey number such as $[-\infty, \infty]$, which is also considered a black number due to the absence of meaningful information. Similarly, reporting the human body temperature in the range of $[13°C, 46°C]$ without context provides no valuable insight and can also be classified as "black" data. In such cases, trimming the data to remove outliers yields a clearer and more useful variable for decision-making purposes. Thus, trimming some of the samples presents a clearer variable for decision-making. The steps for GTPSI is as follows:

Step 1. Goal identification: Determine the objective of the MCDM problem.
Step 2. Obtain the performance values. The performance value y_{ijk} for each alternative A_i, for every criterion C_j, and for every sample S_k is obtained and then placed in a decision table as given in Table 2.
Step 3. Trim the performance values. Before trimming the performance values, the values will be sorted for each criterion, and the δ samples are trimmed of. Both the top and bottom sample are trimmed bye δ and are represented by $S'_{1+\delta}$ and $S'_{z+\delta}$, respectively. This trimmed decision table is represented in Table 3 and is built with a sorted performance value (y'_{ijk}).
Step 4. Grey decision matrix formulation: Converting a decision table to a matrix for matrix operations. For a set of alternatives $A = A_i$ for $i = 1, 2, 3, \ldots, n$ and a set of decision criteria $C = C_j$ for $j = 1, 2, 3, \ldots, m$, $\otimes x_{ij}$ is the grey trimmed performance value of alternative A_i considering criteria C_j.

Criteria (C_j)	C_1					$\dots$	C_j	$\dots$	C_m				
Sample	A_1	$\dots$	A_i	$\dots$	A_n	$\dots$	A_i	$\dots$	A_1	$\dots$	A_i	$\dots$	A_n
S_1	y_{111}	$\dots$	y_{i11}	$\dots$	y_{n11}	$\dots$	y_{ij1}	$\dots$	y_{1m1}	$\dots$	y_{im1}	$\dots$	y_{nm1}
$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$
S_k	y_{11k}	$\dots$	y_{i1k}	$\dots$	y_{i1k}	$\dots$	y_{ijk}	$\dots$	y_{1mk}	$\dots$	y_{imk}	$\dots$	y_{nmk}
$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$
S_z	y_{11z}	$\dots$	y_{i1z}	$\dots$	y_{i1z}	$\dots$	y_{ijz}	$\dots$	y_{1mz}	$\dots$	y_{imz}	$\dots$	y_{nmz}

Table 2. Decision table with Multiple Samples.

Criteria (C_j)	C_1					$\dots$	C_j	$\dots$	C_m				
Index	A_1	$\dots$	A_i	$\dots$	A_n	$\dots$	A_i	$\dots$	A_1	$\dots$	A_i	$\dots$	A_n
$S'_{1+\delta}$	y'_{111}	$\dots$	y'_{i11}	$\dots$	y'_{n11}	$\dots$	y'_{ij1}	$\dots$	y'_{1m1}	$\dots$	y'_{im1}	$\dots$	y'_{nm1}
$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$
S'_k	y'_{11k}	$\dots$	y'_{i1k}	$\dots$	y'_{i1k}	$\dots$	y'_{ijk}	$\dots$	y'_{1mk}	$\dots$	y'_{imk}	$\dots$	y'_{nmk}
$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$
$S'_{z-\delta}$	y'_{11z}	$\dots$	y'_{i1z}	$\dots$	y'_{i1z}	$\dots$	y'_{ijz}	$\dots$	y'_{1mz}	$\dots$	y'_{imz}	$\dots$	y'_{nmz}

Table 3. Trimmed Decision Table with Sorted Samples.

$$\otimes Y = \begin{bmatrix} \otimes y_{11} & \cdots & \otimes y_{1j} & \cdots & \otimes y_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \otimes y_{i1} & \cdots & \otimes y_{ij} & \cdots & \otimes y_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \otimes y_{m1} & \cdots & \otimes y_{mj} & \cdots & \otimes y_{mn} \end{bmatrix} \tag{12}$$

where

$$\otimes y_{ij} = \left[\underline{y}_{ij}, \bar{y}_{ij}\right] = \left[\min_k(y'_{ijk}), \max_k(y'_{ijk})\right] \tag{13}$$

Step 5. Kernel Decision matrix computation: The kernel of the grey trimmed performance value is calculated using Eq. (14)

$$x_{ij} = \underline{y}_{ij}(1-\omega) + \bar{y}_{ij}\omega \tag{14}$$

where ω is the whitening coefficient.

Step 6. Data normalization: This exactly the same normalization of the classical PSI, here Eq. (8).
Step 7. Weighted data normalization: This is a product of the weights and the normalized data, i.e. $R = w'_j(h) \times r_{ij}$
Step 8. Preference variation value (Ψ_j) computation: This is computation is the same as Eq. (9).
Step 9. Overall preference value computation: This is an objective weight computed using Eq. (10).
Step 10. Combined the subjective weight. The subjective weights are obtained from experts and computed using any of the MCDM weighting methods and combined using the Eq. (15),

$$\Psi'_j = \Psi_j(1-\lambda) + W_j\lambda \tag{15}$$

where λ is the weighting coefficient that swings the weight from the traditional PSI to subjective weights.

Step 11. Preference Selection Index (PSI) computation: Here PSI (I_i) is,

$$I_i = \sum_{j=1}^{M} \left(R_{ij} \times \Psi'_j \right) \quad (16)$$

Step 12. Alternative ranking: The PSI is ranked, alternative with this highest PSI (I_i) is the best.

Most importantly, all methods were performed in accordance with the Xuzhou University of Techology guidelines and regulations, and these were provided and approved by the Office of Academic Affairs, and Office of Student Affairs, School of Management Engineering, Xuzhou University of Technology.

Result and analysis

The team running maintenance of the university dormitory of the university considered it fit to get input from students before embarking on the renovation project of the university dormitory. Thus, a notice was put up for the student to submit their design. For privacy, the 3D model of the old dorm is presented in Fig. 2. The submitted design underwent some filtering to ensure the designs were not retrofitting; afterwards, five designs $(A_1$ to $A_5)$ were chosen for further evaluation using the GTPSI method in Sect. "Evaluation methods" in. The flowchart of the research is presented in Fig. 3. Top in the process is the hierarchical model for the evaluation was developed as given in Fig. 1, which consists of 4 first-level criteria (C_1 to C_5) and 12 second-level criteria (C_{1-1} to C_{4-3}).

Criteria weighting

The methods used in computing the subjective weight of the DMs are those presented in Sect. "Weighting methods". Five experts (DM_1 to DM_5) were requested to grade the criteria in percentages based on their importance. These experts were architects, interior designer engineers, a professor of mechanical engineering whose research area is HVAC (Heating, Ventilation, and Air Conditioning) systems, a sustainability consultant, and an interior designer contractor manager. The expert criteria scores are given in Table 4. Then, the grey weights are obtained using Eqs. (1) and (2), which is $\otimes L'$ to $\otimes L''$, respective. Then, the kernel (*H*) of the grey weight Eq. (3), $\omega = 0.5$. Finally, the effective subjective weight is obtained using Eq. (6) is

$$w_j^{'}(h) = 0.0806, 0.1165, 0.0806, 0.0899, 0.1199, 0.1049, 0.0562, 0.0702, 0.0773, 0.0526, 0.0657, 0.0854. \quad (17)$$

GTPSI for evaluating renovation design

After the preliminary screening process, five designs were chosen for further evaluation then these designs is presented, and the following are the design descriptions:

Fig. 2. Model of the current dormitory (Source by authors using SketchUp Version 21.0, see www.sketchup.com).

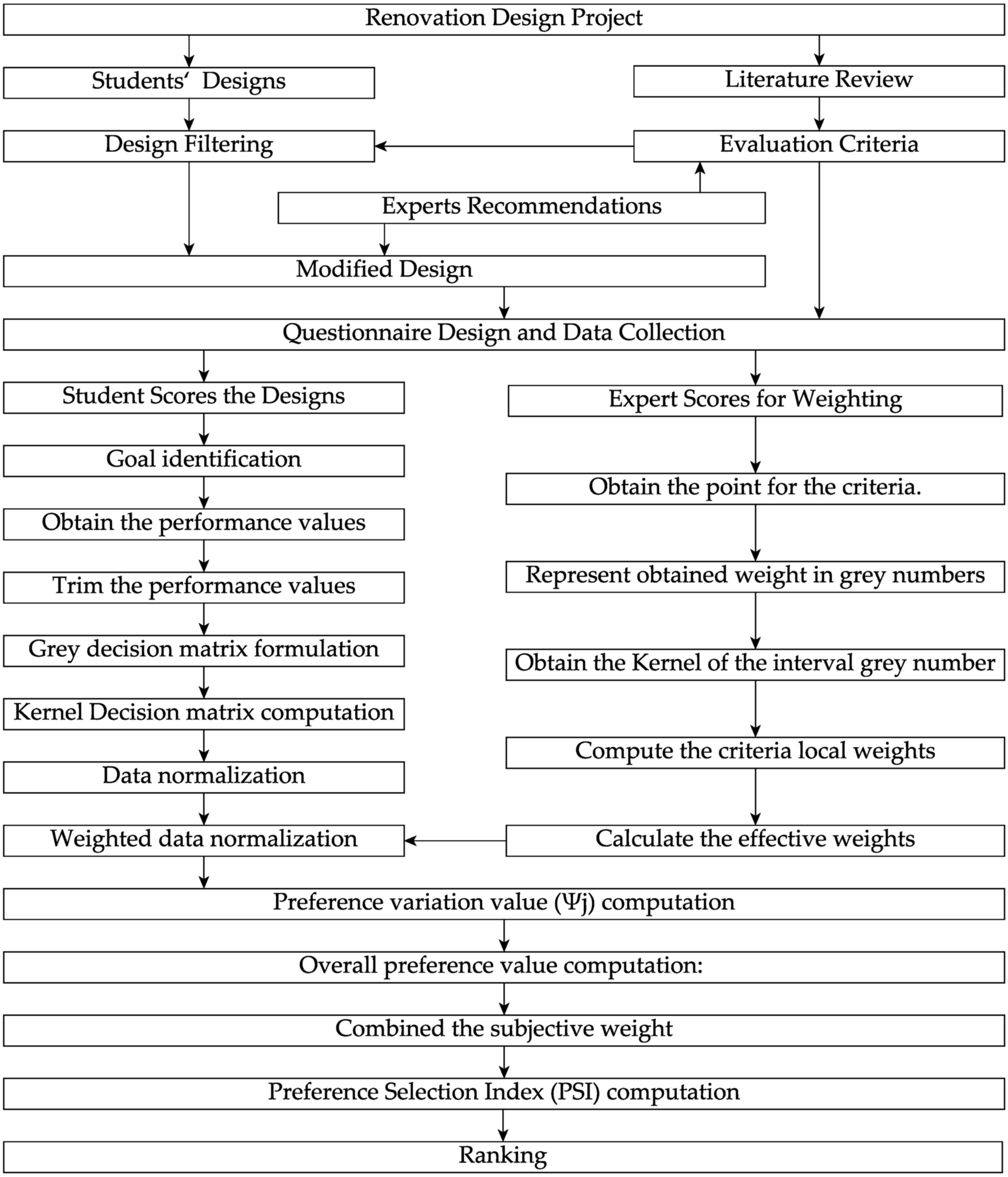

Fig. 3. Flow chart of dormitory renovation.

A_1: The first design is the architectural facade utilizing traditional Chinese mortise and tenon craftsmanship, presenting a unified and simplistic appearance, reflecting traditional characteristics and regional culture. The design also incorporates elements of ancient architectural eaves, symbolizing unity and harmony, aligning with dormitory culture and needs. Using wooden materials creates a warm and comfortable atmosphere, while the side concrete walls add a solemn beauty. The lattice design cleverly conceals air conditioning, meeting modern minimalist aesthetics. Lastly, an open balcony improves lighting and ventilation, enhancing the living environment and opportunities for interaction. See Fig. 4.

A_2: The second design optimizes for the high summer temperatures in Xuzhou, enhancing the architectural wall design for green energy efficiency. Optimizations include adding shading vertical poles, recessed window designs, ventilated roof insulation, and glass walls with air layers, granting the building good insulation and temperature adaptability, reducing air conditioning use, energy consumption, and carbon emissions. Moreover, through unit design, material matching, wood lattice application, and partial expansion, the building's appearance is enriched, offering more activity space. See Fig. 5.

Criteria/Experts	DM_1	DM_2	DM_3	DM_4	DM_5	$\otimes L$	*H*
C_1	50	80	100	80	70	[50, 100]	75
C_2	90	80	100	85	70	[70, 100]	85
C_3	30	80	60	80	60	[30, 80]	55
C_4	10	90	20	80	100	[10, 100]	55
C_{1-1}	30	80	10	80	70	[10, 80]	45
C_{1-2}	30	100	80	80	70	[30, 100]	65
C_{1-3}	10	80	50	50	50	[10, 80]	45
C_{2-1}	50	90	30	70	70	[30, 90]	120
C_{2-2}	90	80	80	70	90	[70, 90]	80
C_{2-3}	95	100	40	85	100	[40, 100]	70
C_{3-1}	10	70	40	65	70	[10, 70]	40
C_{3-2}	30	70	60	60	60	[30, 70]	50
C_{3-3}	30	70	80	70	50	[30, 80]	55
C_{4-1}	50	70	10	70	70	[10, 70]	40
C_{4-2}	50	80	20	70	50	[20, 80]	50
C_{4-3}	30	80	40	75	100	[30, 100]	50

Table 4. Decision maker weighting scores.

(a) (b)

Fig. 4. (**a**) Front view of Design-1 (**b**) Back view of Design-1 (Source by authors using D5 Render 2.6, see www.d5render.com/).

A_3: The third design terms of green energy and aesthetic form are as follows. Firstly, for green energy, the scheme installs solar photovoltaic panels on the exterior walls to reduce reliance on traditional energy sources and uses a composite wall structure embedded with rock wool and a vapour barrier to improve insulation. Secondly, in aesthetic form, the staggered arrangement of solar panels adds variety and dynamism. Using glass curtain walls in stairwells emphasizes vertical composition, contrasting with horizontal elements. In contrast, combining red bricks, concrete, and glass further enhances the building's beauty and layers. See Fig. 6.

A_4: The four designs in terms of green energy and aesthetic form are as follows. Firstly, for green energy, the design of recessed windows increases the building's exterior surface area, facilitating summer heat dissipation. The combination of grilles and potted plants beautifies the facade while utilizing plants' photosynthesis to absorb carbon emissions and remove some heat. The use of light-coloured materials for wall surfaces reflects solar radiation, helping to maintain stable indoor temperatures. Secondly, in aesthetic form, the overall white design harmonizes with the surrounding buildings, with a perfect balance between white and light yellow wood colours. The window frame design highlights dormitory features, presenting a dynamic beauty with changes in time and seasons. The arrangement of grilles and plants is both economical and aesthetically pleasing. See Fig. 7.

A_5: The fifth design is an architectural design that emphasizes reducing pollution, green ecology, and sustainable development. This includes selecting renewable or recyclable materials, employing low-impact construction techniques, optimizing energy and resource efficiency, and encouraging user involvement in managing and maintaining green buildings. In addition, emphasizing the functionality and aesthetic value of buildings, integrating green elements like green roofs, natural lighting, and ventilation while continually innovating

(a) (b)

Fig. 5. (**a**) Front view of Design-2 (**b**) Back view of Design-2 (Source by authors using V-ray Version 2021, see www.chaos.com).

(a) (b)

Fig. 6. (**a**) Front view of Design-3 (**b**) Back view of Design-3 (Source by authors using V-ray Version 2021, see www.chaos.com).

(a) (b)

Fig. 7. (**a**) Front view of Design-4 (**b**) Back view of Design-4 (Source by authors using SketchUp Version 21.0, see www.sketchup.com).

with passive design, renewable energy, and ecological technologies to achieve harmonious coexistence with nature, promoting sustainable development. The goal of architects and designers is to integrate environmental and sustainable development concepts into every aspect of the design, creating efficient, eco-friendly, practical, and beautiful architectural design schemes. See Fig. 8.

(a) (b)

Fig. 8. (**a**) Front view of Design-5 (**b**) Back view of Design-5 (Source by authors using AutoCAD Version 2023, see www.autodesk.com).

Criteria	C_{1-1}					C_{1-2}						C_{3-4}				
Design/Student	A_1	A_2	A_3	A_4	A_5	A_1	A_2	A_3	A_4	A_5	...	A_1	A_2	A_3	A_4	A_5
1	80	80	80	80	80	80	80	80	80	80	...	80	80	80	80	80
2	60	60	60	80	70	60	60	60	80	70	...	60	60	60	80	70
3	100	100	100	100	100	100	100	100	100	100	...	100	100	100	100	100
4	70	70	80	75	75	70	70	80	75	75	...	90	90	90	90	90
5	90	70	68	85	85	91	85	83	88	90	...	95	85	86	92	90
6	80	60	60	60	80	60	80	80	80	60	...	80	80	80	80	80
7	80	100	80	80	80	100	80	80	80	80	...	80	80	80	80	80
8	60	70	70	80	50	60	60	60	80	80	...	60	80	80	60	60
9	60	60	60	100	60	60	60	60	100	60	...	70	80	50	90	50
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋱	⋮	⋮	⋮	⋮	⋮
147	80	80	80	80	80	80	80	80	80	80	...	80	80	80	80	80

Table 5. Raw percentage point for student about the design options.

An online questionnaire created for this current study was used to obtain the percentage points (0 to 100%) from students in two classes, a class of 60 and a class of 90. The percentage point method closely aligns with the point allocation approach applied by Esangbedo et al[58–60]. Throughout the research process, we rigorously adhered to the principles of content validity, construct validity, and face validity, which are essential to the credibility of our findings. These measures were ensured within the framework of a hierarchical model for decision-making in construction project evaluation. More importantly, informed consent was obtained from these students before participation in filling out the questionnaire. All methods were carried out in accordance with relevant guidelines and regulations. Specifically, the research pertained to the following concerning participants (students): **no** identification information was collected; **no** human transplantation was conducted; the studies were **not** involved with vulnerable groups; sex and gender were **not** part of this research. To reiterate, participation was voluntary and anonymous, and students could withdraw their participation by not submitting the questionnaire. The students' preferences were gathered through a web-based questionnaire distributed via a paper-based quick response (QR) code to ensure broad accessibility. To prevent multiple submissions from a single student and to maintain the integrity of the data, we incorporated a validation mechanism through WeChat. By limiting responses to a single submission per authenticated WeChat account, we aimed to eliminate duplicate entries and ensure that each response was unique. Just before their lesson began, three students were absent from class. A total of 147 students were requested to answer the questionnaire. Table 5 gives the data obtained from the 147 students, and each student answered 60 questions corresponding to each 60 performance value y_{ijk}. There were no missing values because the online questionnaire had validation before submission.

It should be noted that the hierarchical model can be more detailed, but it will result in more questions the student needs to answer in the questionnaire that will match the respective number of alternatives and criteria.

Upon examining the collected data, we observed that there were unattended responses. For example, one student gave 1% to all the questions, and the other gave 100%. Thus, the data was clean by removing responses for the students that had a variance of zero. Unfortunately, 16 students provided unattended responses. In total, 131 samples were sorted as given in Table 6 and trimmed based on Step 3 of Sect. "Weighting methods" as given in Table 7. Figures 9 and 10 show the effect of trimming the sample used for evaluation, providing a tighter range for representing the rating of students as interval grey numbers.

The performance values in Table 7 are converted to interval grey numbers using Eqs. (1) and (2), a grey decision table is constructed as given in Table 8. Subsequently, a grey decision matrix is constructed using Eq. (12).

Thus, the decision matrix based on Eq. (12) is used to obtain

$$\otimes Y = \begin{bmatrix} [50,90] & [60,90] & [55,90] & [55,90] & [60,90] & \cdots & [60,90] \\ [60,95] & [60,91] & [60,90] & [60,90] & [60,94] & \cdots & [60,95] \\ [60,90] & [60,90] & [60,90] & [60,90] & [60,90] & \cdots & [60,90] \\ [60,100] & [60,90] & [60,95] & [60,95] & [60,90] & \cdots & [65,92] \\ [50,90] & [50,90] & [60,90] & [60,90] & [60,90] & \cdots & [60,90] \end{bmatrix} \tag{18}$$

Thus, the kernel decision matrix drawn from Table 8 is obtain using Eq. (14)

$$X = \begin{bmatrix} 70 & 75 & 72.5 & 72.5 & 75 & \cdots & 75 \\ 77.5 & 75.5 & 75 & 75 & 77 & \cdots & 77.5 \\ 75 & 75 & 75 & 75 & 75 & \cdots & 75 \\ 80 & 75 & 77.5 & 77.5 & 75 & \cdots & 78.5 \\ 70 & 70 & 75 & 75 & 75 & \cdots & 75 \end{bmatrix} \tag{19}$$

Criteria	C_{1-1}					C_{1-2}						C_{3-4}				
Design/Student	A_1	A_2	A_3	A_4	A_5	A_1	A_2	A_3	A_4	A_5	...	A_1	A_2	A_3	A_4	A_5
S_1	1	12	2	20	3	20	20	20	40	20	...	20	20	20	50	10
S_2	20	20	20	30	20	20	30	20	50	20	...	20	20	20	56	20
S_3	20	20	20	50	20	40	35	20	50	20	...	25	30	25	60	20
S_4	20	30	20	50	20	50	40	20	50	38	...	30	35	40	60	20
S_5	20	40	50	50	20	50	50	20	60	40	...	50	50	50	60	20
S_6	40	40	50	50	20	50	60	35	60	50	...	50	58	50	60	20
S_7	40	50	50	50	20	50	60	48	60	50	...	50	60	50	60	35
S_8	40	50	50	60	40	50	60	50	60	50	...	60	60	60	60	50
S_9	45	50	60	60	40	60	60	60	60	50	...	60	60	60	60	50
S_{10}	45	50	60	60	50	60	60	60	60	50	...	60	60	60	60	59
S_{11}	50	60	60	60	50	60	60	60	60	50	...	60	60	60	65	60
S_{12}	50	60	60	60	50	60	60	60	60	55	...	60	60	60	65	60
S_{13}	50	60	60	60	50	60	60	60	60	60	...	60	60	60	69	60
S_{14}	50	60	60	60	50	60	60	60	60	60	...	60	60	60	70	60
S_{15}	60	60	60	60	50	60	60	60	60	60	...	60	60	60	70	60
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
S_{117}	90	90	88	95	90	90	90	88	90	90	...	90	90	90	90	90
S_{118}	90	90	90	95	90	90	90	88	90	90	...	90	90	90	90	90
S_{119}	90	90	90	98	90	90	90	88	90	90	...	90	91	90	90	90
S_{120}	90	90	90	99	90	90	90	90	90	90	...	90	95	90	91	90
S_{121}	90	95	90	100	90	90	91	90	90	90	...	90	95	90	92	90
S_{122}	90	95	90	100	90	90	92	90	92	90	...	90	95	90	92	90
S_{123}	100	95	90	100	100	90	95	90	95	90	...	93	95	90	92	90
S_{124}	100	100	90	100	100	90	95	90	98	90	...	95	95	90	95	90
S_{125}	100	100	95	100	100	91	95	90	99	90	...	95	95	90	96	90
S_{126}	100	100	100	100	100	95	95	90	100	95	...	97	96	92	99	90
S_{127}	100	100	100	100	100	96	98	90	100	100	...	98	96	93	99	92
S_{128}	100	100	100	100	100	100	98	90	100	100	...	99	99	95	100	99
S_{129}	100	100	100	100	100	100	100	90	100	100	...	99	100	98	100	100
S_{130}	100	100	100	100	100	100	100	90	100	100	...	100	100	98	100	100
S_{131}	100	100	100	100	100	100	100	100	100	100	...	100	100	99	100	100

Table 6. Clean sorted decision table.

Criteria	C_{1-1}					C_{1-2}						C_{3-4}				
$S_{k\pm\delta}$/**Design**	A_1	A_2	A_3	A_4	A_5	A_1	A_2	A_3	A_4	A_5	...	A_1	A_2	A_3	A_4	A_5
S_{11}	50	60	60	60	50	60	60	60	60	50	...	60	60	60	65	60
S_{12}	50	60	60	60	50	60	60	60	60	55	...	60	60	60	65	60
S_{13}	50	60	60	60	50	60	60	60	60	60	...	60	60	60	69	60
S_{14}	50	60	60	60	50	60	60	60	60	60	...	60	60	60	70	60
S_{15}	60	60	60	60	50	60	60	60	60	60	...	60	60	60	70	60
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
S_{117}	90	90	88	95	90	90	90	88	90	90	...	90	90	90	90	90
S_{118}	90	90	90	95	90	90	90	88	90	90	...	90	90	90	90	90
S_{119}	90	90	90	98	90	90	90	88	90	90	...	90	91	90	90	90
S_{120}	90	90	90	99	90	90	90	90	90	90	...	90	95	90	91	90
S_{121}	90	95	90	100	90	90	91	90	90	90	...	90	95	90	92	90

Table 7. Trimmed sorted decision table.

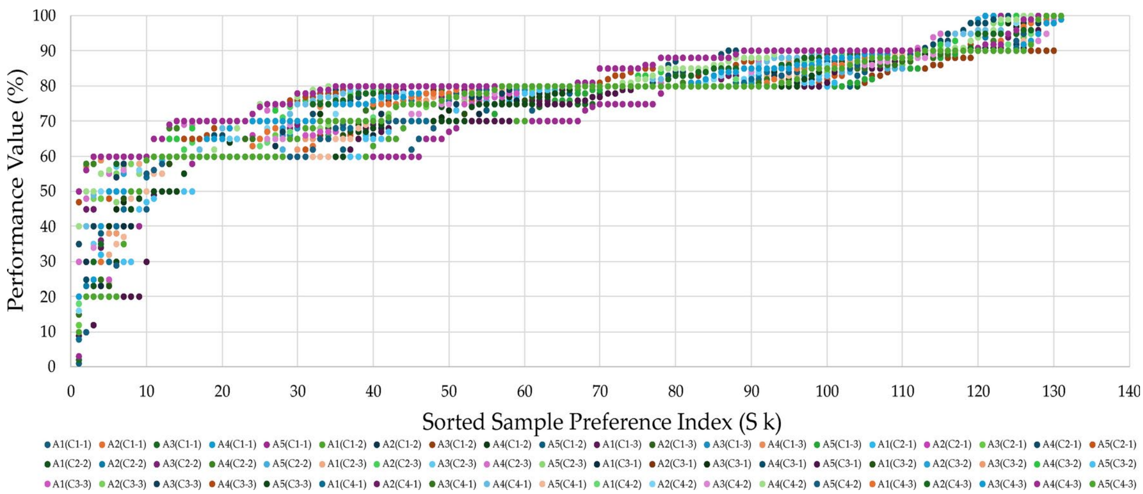

Fig. 9. Untrimmed sorted performance values.

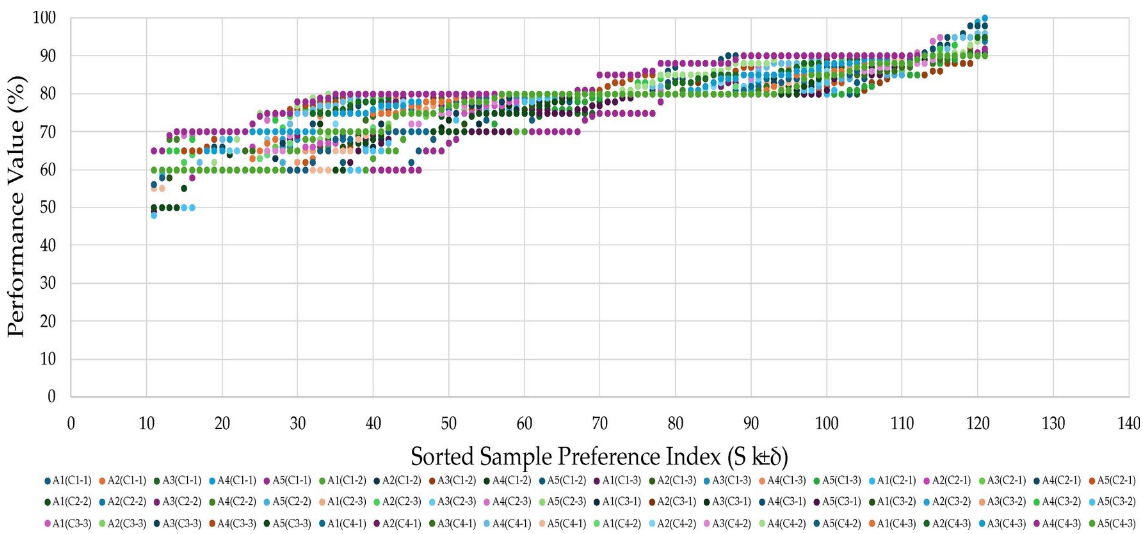

Fig. 10. Trimmed sorted performance values.

	Interval grey numbers					Kernel of the grey numbers				
	A_1	A_2	A_3	A_4	A_5	A_1	A_2	A_3	A_4	A_5
C_{1-1}	[50, 90]	[60, 95]	[60, 90]	[60, 100]	[50, 90]	70	77.5	75	80	70
C_{1-2}	[60, 90]	[60, 91]	[60, 90]	[60, 90]	[50, 90]	75	75.5	75	75	70
C_{1-3}	[55, 90]	[60, 90]	[60, 90]	[60, 95]	[60, 90]	72.5	75	75	77.5	75
C_{2-1}	[55, 90]	[60, 90]	[60, 90]	[60, 95]	[60, 90]	72.5	75	75	77.5	75
C_{2-2}	[60, 90]	[60, 94]	[60, 90]	[60, 90]	[60, 90]	75	77	75	75	75
C_{2-3}	[60, 95]	[60, 95]	[60, 95]	[60, 96]	[60, 95]	77.5	77.5	77.5	78	77.5
C_{3-1}	[50, 92]	[60, 95]	[60, 90]	[60, 98]	[49, 90]	71	77.5	75	79	69.5
C_{3-2}	[50, 90]	[60, 95]	[60, 90]	[60, 95]	[48, 90]	70	77.5	75	77.5	69
C_{3-3}	[60, 90]	[60, 95]	[60, 90]	[60, 95]	[50, 90]	75	77.5	75	77.5	70
C_{4-1}	[55, 90]	[60, 90]	[60, 90]	[60, 96]	[55, 90]	72.5	75	75	78	72.5
C_{4-2}	[60, 90]	[60, 95]	[60, 90]	[60, 95]	[56, 90]	75	77.5	75	77.5	73
C_{4-3}	[60, 90]	[60, 95]	[60, 90]	[65, 92]	[60, 90]	75	77.5	75	78.5	75

Table 8. Grey number with kernel decision table.

The decision matrix (Eq. (19)) is normalized using Eq. (8):

$$R = \begin{bmatrix} 0.875 & 0.9934 & 0.9355 & 0.9355 & 0.974 & \cdots & 0.9554 \\ 0.9688 & 1 & 0.9677 & 0.9677 & 1 & \cdots & 0.9873 \\ 0.9375 & 0.9934 & 0.9677 & 0.9677 & 0.974 & \cdots & 0.9554 \\ 1 & 0.9934 & 1 & 1 & 0.974 & \cdots & 1 \\ 0.875 & 0.9272 & 0.9677 & 0.9677 & 0.974 & \cdots & 0.9554 \end{bmatrix}$$

The Preference Variation Value (*PV*) is obtained using Eq. (9),

$$PV_j = [0.0125 \quad 0.0163 \quad 0.0087 \quad 0.0087 \quad 0.0120 \quad 0.0203 \quad 0.0112 \quad 0.0132 \quad 0.0107 \quad 0.0066 \quad 0.0122 \quad 0.0096] \tag{20}$$

The overall preference value is obtained using Eq. (10),

$$\Phi_j = [0.0806 \quad 0.1165 \quad 0.0806 \quad 0.0899 \quad 0.1199 \quad 0.1049 \quad 0.0562 \quad 0.0702 \quad 0.0773 \quad 0.0526 \quad 0.0657 \quad 0.0854] \tag{21}$$

The experts' subjective weights are given in Eq. (17), and the objective weights are obtained using Eq. (21). Since we have 12 second-level criteria, equal weight is 1/12. Figure 11 shows a graph of the weight obtained from the traditional PSI, known as the overall preference value (objective weights), experts' weight (subjective weights) and equal weights.

In decision-making when experts are available, the use of equal-weight is less than ideal. From Fig. 11, it can be noticed that the objective weight and equal-weights are closely similar since both are approximately the same line. Therefore, in this research we set lamba to one ($\lambda = 1$).

$$\Psi'_j = [0.0806 \quad 0.1165 \quad 0.0806 \quad 0.0899 \quad 0.1199 \quad 0.1049 \quad 0.0562 \quad 0.0702 \quad 0.0773 \quad 0.0526 \quad 0.0657 \quad 0.0854] \tag{22}$$

The Preference Selection Index (PSI) is calulated using Eq. (16).

$$I = \begin{bmatrix} 0.9522 & 0.9847 & 0.967 & 0.9937 & 0.9367 \end{bmatrix}^{\mathrm{T}} \tag{23}$$

Ranking the Designs: Design-4 (A_4) is ranked the first position, Design-2 (A_2) is ranked the second position, Design-3 (A_3) is ranked the third position, Design-1 $(A_1)$is ranked the fourth position, Design-5 (A_5) is ranked the fifth position. In other words, Design-4 (A_4) is the best.

The classical PSI method only uses objective weights. From Fig. 11, based on the student's preferences, the objective weight can be approximated to be equally weighted, as shown by an almost flat blue line. The subjective weights of experts, represented by the orange line, indicate that the most important criterion is *Practicability* (C_{2-2}), which is at the peak of the weight line. On the other hand, modernization has rendered the pursuit of traditional Chinese architectural design passive, as indicated in the valley of the line graph by *Culture* (C_{4-1}). Despite having construction experts assign weights to the criteria, weights drawn from students' preferences cannot be ignored. Thus, the kernel weights, represented by the green line that strikes a balance between the experts and students, are used for evaluating the design.

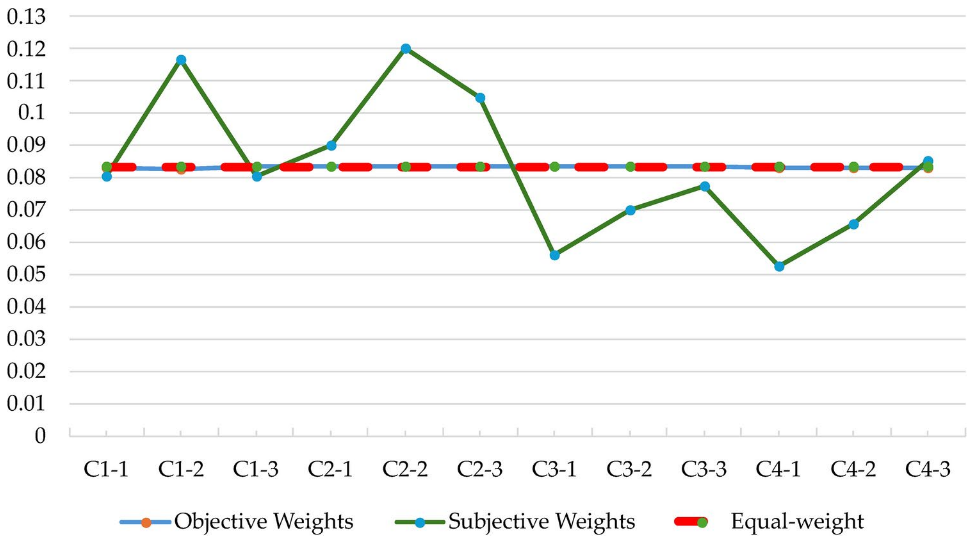

Fig. 11. Weights for evaluating designs.

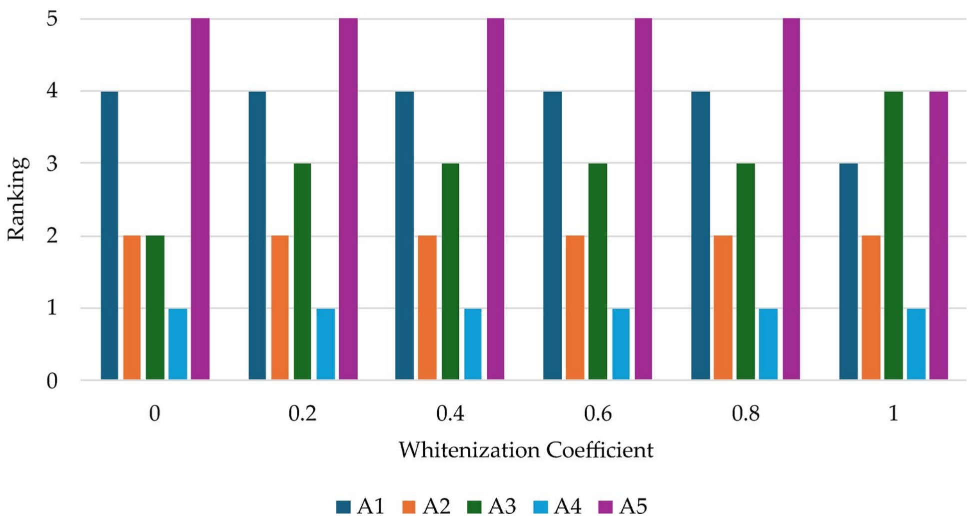

Fig. 12. Rankings comparison.

Comparing Figs. 9 and 10, it can be observed that the latter used a wider distance between the lower and upper bounds of the interval grey number if not trimmed. After trimming, a tighter range between the lower and upper bounds is obtained, which is used for evaluation. It should be noted that although the decision table presented in this research appears flat, it is not a matrix. In fact, it is a tensor, i.e., one plane for alternatives, one plane for weights, and another for samples, i.e., the students.

We evaluated the robustness of our results by conducting a whitening sensitivity analysis, where the whitening coefficient ω varies from 0 to 1. This approach allowed us to thoroughly examine the performance across the entire spectrum-from the lower to the upper bounds of the grey number. As illustrated in Fig. 12, the analysis revealed a remarkably stable ranking, with the notable exceptions being the extreme values of the whitening coefficient ω at 0 and 1. Specifically, when $\omega = 0$, both *Design-2* (A_2) and *Design-3* (A_3) were tied for the second position. Conversely, at $\omega = 1$, *Design-3* (A_3) and *Design-4* (A_4) emerged. Despite these variations at the boundaries, the ranking remained consistent across the rest of the range, indicating a relatively stable ranking overall.

Comparison with compensatory and non-compensatory MCDM methods

For a more balanced comparison of both compensatory and non-compensatory MCDM evaluation methods, specifically TOPSIS and ELECTRE-III (an outranking method), analysis is conducted.

TOPSIS for rankings confirmation

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is chosen for comparative evaluation due to its status as a **preference** evaluation method. This technique, which was developed by Ching-Lai Hwang and Yoon is predicated on the notion that the selected alternative ought to be at the minimal geometric distance from the positive ideal solution (PIS) and at the maximal geometric distance from the negative ideal solution (NIS). The decision matrix as given in Eq. (19) is to be normalized into a vector form, as stipulated by the vector normalization in Eq. (24).

$$x_{ij}^{*}\frac{x_{ij}}{\sqrt{\sum_{i=1}^{n}x_{ij}^{2}}} \quad (24)$$

Then, we obtain the normalized decision matrix as given in Eq. (25).

$$X^{*}=\begin{pmatrix} 0.4196 & 0.4525 & 0.4427 & 0.4428 & 0.4425 & \cdots & 0.4531 \\ 0.4646 & 0.4555 & 0.4196 & 0.4652 & 0.4591 & \cdots & 0.4477 \\ 0.4496 & 0.4525 & 0.463 & 0.4204 & 0.437 & \cdots & 0.4396 \\ 0.4795 & 0.4525 & 0.4746 & 0.4764 & 0.4702 & \cdots & 0.4585 \\ 0.4196 & 0.4223 & 0.434 & 0.4288 & 0.4259 & \cdots & 0.4369 \end{pmatrix} \quad (25)$$

Next, we compute the weighted normalization matrix X', calculating each element of the matrix as $x'_{ij}=w_j\times x^{*}_{ij}$, where w_j is the weight of the j^{th} criterion.

$$X'=\begin{pmatrix} 0.0348 & 0.0458 & 0.0367 & 0.0384 & 0.0449 & \cdots & 0.0378 \\ 0.0385 & 0.0461 & 0.0348 & 0.0403 & 0.0466 & \cdots & 0.0373 \\ 0.0373 & 0.0458 & 0.0384 & 0.0365 & 0.0444 & \cdots & 0.0367 \\ 0.0398 & 0.0458 & 0.0393 & 0.0413 & 0.0477 & \cdots & 0.0382 \\ 0.0348 & 0.0428 & 0.036 & 0.0372 & 0.0432 & \cdots & 0.0364 \end{pmatrix}.$$

We obtain the ideal solution using Eq. (26) and the anti-ideal solution using Eq. (27).

$$X^{+}=\left\{\left(\max_i v_{ij}\mid j\in J^{+}\right),\left(\max_i v_{ij}\mid j\in J^{-}\right)\mid i=1,\ldots,m\right\}=\{x_1^{+},\ldots,x_j^{+},\ldots,x_n^{+}\} \quad (26)$$

$$X^{+}=\begin{pmatrix}0.0398 & 0.0461 & 0.0393 & 0.0413 & 0.0477 & \cdots & 0.0382\end{pmatrix}$$

$$X^{-}=\left\{\left(\max_i v_{ij}\mid j\in J^{+}\right),\left(\max_i v_{ij}\mid j\in J^{-}\right)\mid i=1,\ldots,m\right\}=\{x_1^{-},\ldots,x_j^{-},\ldots,x_n^{-}\} \quad (27)$$

$$X^{-}=\begin{pmatrix}0.0348 & 0.0428 & 0.0348 & 0.0365 & 0.0432 & \cdots & 0.0364\end{pmatrix}$$

We calculate the distances of the alternatives from the ideal solution using Eq. (28) and from the anti-ideal solution using Eq. (29), respectively.

$$S_{i^{+}}=\sqrt{\sum_{j=1}^{n}\left(x'_{ij}-x_j^{+}\right)^2} \quad (28)$$

$$S^{+}=\begin{pmatrix}0.0087 & 0.0053 & 0.0099 & 0.0003 & 0.0114\end{pmatrix}^{\mathrm{T}}$$

$$S_{i^{-}}=\sqrt{\sum_{j=1}^{n}\left(x'_{ij}-x_j^{-}\right)^2} \quad (29)$$

$$S^{-}=\begin{pmatrix}0.0058 & 0.0099 & 0.0056 & 0.0129 & 0.0035\end{pmatrix}^{\mathrm{T}}$$

Finally, we determine and rank the closeness values for each alternative using Eq. (30).

$$C_{i^{*}}=\frac{S_{i^{-}}}{(S_{i^{+}}+S_{i^{-}})} \quad (30)$$

$$C^{+}=\begin{pmatrix}0.4004 & 0.6523 & 0.3595 & 0.9769 & 0.2343\end{pmatrix}^{\mathrm{T}}$$

According to the rankings obtained from the TOPSIS method, the design with the highest closeness value is considered the best. The rankings are as follows: *Design-4* (A_4) holds the first position, *Design-2* (A_2) the second, *Design-3* (A_3) the third, *Design-1* (A_1) the fourth, and *Design-5* (A_5) the fifth. This confirms the ranking using the GTPSI method.

ELECTRE III confirmation
ELECTRE III was developed by Bernard Roy in the 1970s[61]. Bernard Roy was a French mathematician and a pioneer in the field of MCDM. Roy developed the ELECTRE (ELimination Et Choix Traduisant la REalité), translated as "Elimination and Choice Expressing Reality," which is a family of methods with various versions such as ELECTRE I, II, III, IV, and TRI, each tailored to different types of decision-making problems and scenarios. ELECTRE III as reported by Marzouk[62] is applied here. After obtaining the vector normalized decision matrix in Eq. (25) and the weighted normalized decision matrix in Eq.

the subsequent steps for ranking alternatives in the ELECTRE-III method are as follows.

We calculated the concordance index ($C(a, b)$), which measures the degree to which alternative a is at least as good as alternative b across all criteria. For each criterion k, compare the performance of alternatives a and b using the preference, indifference, and veto thresholds (p_k, q_k, and v_k), using Eq. (31) and result is give in Eq. (32)

$$C_k(a,b) = \frac{\sum_{k \in J(a,b)} w_k}{\sum_{k=1}^{n} w_k} \tag{31}$$

where: w_k is the weight of criterion k, and $J(a, b)$ is the set of criteria for which a is at least as good as b (satisfying $d_k(a,b) \leq p_k$).

$$C_k(a,b) = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \end{array} \begin{array}{c} \begin{array}{ccccc} A_1 & A_2 & A_3 & A_4 & A_5 \end{array} \\ \begin{pmatrix} 0.0 & 1.0 & 1.0 & 1.0 & 1.0 \\ 1.0 & 0.0 & 1.0 & 1.0 & 1.0 \\ 1.0 & 1.0 & 0.0 & 1.0 & 1.0 \\ 1.0 & 1.0 & 1.0 & 0.0 & 1.0 \\ 1.0 & 1.0 & 1.0 & 1.0 & 0.0 \end{pmatrix} \end{array} \tag{32}$$

Similarly, we calculated the discordance Index ($D(a, b)$), which is alternative b is much better than a for any criterion k, using Eq. (33) as given in Eq. (34).

$$D_k(a,b) = \begin{cases} 0 & \text{if } d_k(a,b) \leq p_k \\ \frac{d_k(a,b)-p_k}{v_k-p_k} & \text{if } p_k < d_k(a,b) < v_k \\ 1 & \text{if } d_k(a,b) \geq v_k \end{cases} \tag{33}$$

where: $d_k(a,b) = f_k(b) - f_k(a)$ is the difference in performance of a and b for criterion k.

$$D_k(a,b) = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \end{array} \begin{array}{c} \begin{array}{ccccc} A_1 & A_2 & A_3 & A_4 & A_5 \end{array} \\ \begin{pmatrix} 0.0000 & 0.0421 & 0.0222 & 0.0421 & 0.0199 \\ 0.0000 & 0.0000 & 0.0073 & 0.0146 & 0.0000 \\ 0.0082 & 0.0199 & 0.0000 & 0.0199 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 0.0366 & 0.0549 & 0.0412 & 0.0560 & 0.0000 \end{pmatrix} \end{array} \tag{34}$$

Then we determined the credibility index ($\sigma(a,b)$), a combination of the concordance and discordance indices, reflecting the strength of the assertion that a is at least as good as b. This computed using Eq. (35), considers both the agreement and disagreement between the alternatives, and the index is given in Eq. (36).

$$\sigma(a,b) = C(a,b) \times \prod_{k=1}^{n} (1 - D_k(a,b))^{\frac{w_k}{\sum_{k=1}^{n} w_k}} \tag{35}$$

$$\sigma(a,b) = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \end{array} \begin{array}{c} \begin{array}{ccccc} A_1 & A_2 & A_3 & A_4 & A_5 \end{array} \\ \begin{pmatrix} 0.0000 & 0.9579 & 0.9778 & 0.9579 & 0.9801 \\ 1.0000 & 0.0000 & 0.9927 & 0.9854 & 1.0000 \\ 0.9918 & 0.9801 & 0.0000 & 0.9801 & 1.0000 \\ 1.0000 & 1.0000 & 1.0000 & 0.0000 & 1.0000 \\ 0.9634 & 0.9451 & 0.9588 & 0.9440 & 0.0000 \end{pmatrix} \end{array} \tag{36}$$

$$\text{Credibility Score for } A_i = \sum_{\substack{j=1 \\ j \neq i}}^{m} \sigma(A_i, A_j) \tag{37}$$

where $\sigma(A_i, A_j)$ the credibility index for the pair alternative A_i and A_j, m is the total number of alternatives. Therefore, $A_1 = 3.8737$, $A_2 = 3.9781$, $A_3 = 3.9520$, $A_4 = 4.0000$, $A_5 = 3.8114$.

Next, we performed the distillation procedure, which is in two folds:

- The Descending Distillation , A_4:= 4.000 (Highest) , A_2:= 3.978 , A_3:= 3.952 , A_1:= 3.874 , A_5:= 3.811 (Lowest) The descending distillation results in the following ranking is $A_4 > A_2 > A_3 > A_1 > A_5$
- The Ascending Distillation A_5 = 3.811 (Lowest) , A_1 = 3.874 , A_3 = 3.952 , A_2 = 3.978 , A_4 = 4.000 (Highest) The ascending distillation results in the following ranking is $A_5 < A_1 < A_3 < A_2 < A_4$Lastly, we performed a complete ranking based on both descending and ascending distillation processes. Since the results of both the descending and ascending distillations are consistent, the final ranking of the alternatives is as follows: $A_4 > A_2 > A_3 > A_1 > A_5$. This means that *Design-4* (A_4) is ranked in the first position, *Design-2* (A_2) is ranked second, *Design-3* (A_3) is ranked third, *Design-1* (A_1) is fourth, and *Design-5* (A_5) occupies the fifth positions.

Table 9 demonstrates a perfect correlation of the rankings obtained using GTPSI, TOPSIS, and ELECTRE-III methods. The Spearman's rho (ρ) and Kendall's Tau-*B* (τ) correlation coefficients, as shown in Table 9, indicate a perfect correlation using these three methods. It is important to note that the ranking decision matrix (decision table) was computed after the large performance data were trimmed. This highlights the effectiveness of grey-trimmed MCDM methods in handling large-scale group decision-making scenarios.

Conclusion

This research introduces the GTPSI, a novel MCDM method that combines students' objective preferences with professionals' subjective expertise for evaluating university dormitory renovation designs. Unlike traditional approaches that may overlook or inaccurately assume student preferences, the GTPSI method directly incorporates these preferences while mitigating noise from non-serious participants by trimming extreme responses. This integration of grey numbers for interval representation allows for a more accurate and inclusive evaluation of renovation alternatives.

Additionally, this paper highlights the importance of involving a large group of stakeholders in the decision-making process to ensure that the remodelling project meets the needs and preferences of the users. The GTPSI can be applied to other large-scale decision-making problems where there is a need to consider multiple criteria and a large number of stakeholders.

The proposed GTPSI has several advantages over traditional methods. Firstly, it takes into account the uncertainty and vagueness of the decision-making process, which is common in complex projects like building remodelling. Secondly, it allows for a more democratic and inclusive decision-making process by involving a larger group of stakeholders. Finally, it provides a more reliable weight calculation that is not affected by outliers or extreme values.

In conclusion, the GTPSI presented in this paper offers a promising approach to remodelling old buildings. By considering multiple criteria and involving a group's preferences, this method can maximize the use of resources while ensuring that the final design meets the needs and preferences of the users. One primary limitation of the research is that it excludes the final design used for the renovation after embarrassing the student's design concept.

Additional information

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Data availability

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request. Moses Olabhele Esangbedo can be contacted for more details, moses@xzit.edu.cn, +86-15109289227.

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	Correlation	GTPSI	TOPSIS	ELECTRE–II
	Spearman's rho	–		
GTPSI	Kendall's Tau B	–		
	Weighted Correlation (r_w)	–		
	WS-Coefficient	–		
TOPSIS	Spearman's rho	1	–	
	Kendall's Tau B	1	–	
	Weighted Correlation (r_w)	1	–	
	WS-Coefficient	1	–	
ELECTRE–III	Spearman's rho	1	1	–
	Kendall's Tau B	1	1	–
	Weighted Correlation (r_w)	1	1	–
	WS-Coefficient	1	1	–

Table 9. Correlation of MCDM methods.

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Author contributions

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Declarations

Competing interests

The authors declare no competing interests.

Ethics approval and consent to participate

All methods were conducted in accordance with the guidelines and regulations of Xuzhou University of Technology. Approval for the study was obtained from the Office of Academic Affairs and the Office of Student Affairs, School of Management Engineering, Xuzhou University of Technology. All participants were over 18 years of age, and their participation in the study was entirely voluntary. Informed consent was obtained from all participants prior to completing the questionnaire, with the option to withdraw at any point before submission, and data were anonymously obtained.

Additional information

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