Middle School Classroom Furniture Evaluation Model Based on Combinatorial Weighting of Game Theory

Yu Liang, Yihui Yan, and Huiyuan Guan *

Within the context of educational innovation, diversified teaching models impose higher requirements on classroom furniture adaptability. However, conflicting multi-stakeholder demands and configuration imbalances constrain the upgrading of educational spaces. To address this, this study focuses on the "demand-configuration" contradiction and constructs a composite evaluation model integrating the "game theory combined weighting method - fuzzy comprehensive evaluation method - quadrant diagram model". Through improved Analytic Hierarchy Process (AHP) and entropy method game weighting, this approach can balance multi-party weight conflicts, quantify user satisfaction based on fuzzy evaluation, and identify "high demand-low adaptation" core indicators using the quadrant diagram. Taking classroom furniture in M Middle School as a practical case, results demonstrate that the quadrant diagram model accurately identified six core indicators based on comprehensive weights and satisfaction levels, aligning with current key optimization directions for classroom furniture. This validates the model's feasibility and accuracy in resolving contradictions between multi-dimensional demands and actual configurations. The proposed evaluation system provides a framework of "demand deconstruction-efficiency evaluation-design guidance" for educational furniture design, which is applicable to quasi-public product design evaluation fields involving multiple stakeholders such as public medical products, thereby enhancing the matching efficiency between product resource allocation and diverse demands.

DOI: 10.15376/biores.20.2.3971-3995

Keywords: Multi-stakeholder design evaluation model; Middle school classroom furniture; Game theory combinatorial weighting method; Fuzzy method; The quarter graph model

*Contact information: College of Furnishings and Industrial Design, Nanjing Forestry University, Nanjing, Jiangsu Province, China 210037; *Corresponding author: guanhy@njfu.edu.cn*

INTRODUCTION

With the innovation of educational concepts and the diversified development of teaching scenarios, classrooms as core carriers of knowledge transmission have seen their spatial functions and furniture design gradually evolve into critical factors influencing teaching quality, teacher-student experience, and even educational equity (Ke and Chen 2022). However, current classroom furniture systems generally suffer from mismatches between actual configurations and user requirements (Su 2020). On the one hand, modern educational paradigms have extended furniture requirements towards dimensions of flexibility, dynamism, and human-machine interaction adaptability (Ke and Chen 2022), while existing classroom furniture configurations exhibit temporal lag. On the other hand, as defined by Samuelson's (1954) theory of public goods and Rosen and Gayer's (2014) exploration of educational facilities' relationship with public goods, school furniture demonstrates quasi-public goods characteristics, integrating attributes of both public and private products. This public goods nature implies that classroom furniture design involves multiple stakeholders, including educational institutions, teachers, and students (Kariippanon *et al.* 2020). However, current research predominantly focuses on student needs (Fu *et al*. 2024), often neglecting other stakeholders' demands. Studies indicate that end-user preferences alone do not solely determine design success, necessitating consideration of other stakeholders' requirements (Jiao and Zhang 2005). As Wood cautioned, "if these relations are ignored or not understood, the project may enter into an 'uncharted stakeholder minefield' (Wood *et al.* 2012). Furthermore, these stakeholders may exhibit both explicit/implicit conflicts and complementary demand preferences (Camargo *et al.* 2021). For instance, teachers prioritize furniture flexibility and adaptability, while students emphasize comfort (Morris *et al.* 2023). Such demand heterogeneity creates coordination challenges in design evaluation processes, with ambiguous demand prioritization frequently leading to resource misallocation and efficiency losses (Chen *et al.* 2023). This phenomenon demonstrates universality in public goods domains (Chen *et al.* 2025; Wang *et al.* 2025), which is particularly evident in furniture design practice. Specific manifestations include: administrative-led procurement decisions potentially causing functional redundancy and low utilization rates, while market-driven cost-reduction strategies may induce ergonomic deficiencies and health risks. Consequently, divergent stakeholder demands generate varied evaluation criteria for classroom furniture, making the balance of multi-party requirements crucial for advancing furniture design optimization.

However, current furniture design demand assessment suffers from dual limitations. First, user demand evaluation predominantly adopts an isolated analysis paradigm that not only neglects other stakeholders' requirements (Miao *et al.* 2024; Chen and Zhu 2024; (Wang and Chen 2024) but also fails to consider trade-off relationships between stakeholders (Zhao *et al.* 2023; Liang 2024; Xiao *et al.* 2024). Second, existing evaluation research on multi-stakeholder furniture products remains relatively scarce, with no effective solutions proposed to reconcile conflicting demands.

As a consequence, there has been a weak connection among products, users, and teaching methods, which ultimately impedes the development of classroom furniture. Moreover, from the perspective of furniture design and procurement, classroom furniture involves multiple stakeholders, such as educators, student groups, school administration teams, furniture manufacturers, and professional designers. How to coordinate the needs of each subject for classroom furniture to guide the design evaluation still needs discussion.

The demand assessment of classroom furniture is closely related to multi-criteria decision analysis (MCDA) and comprehensive evaluation research. The game theory combined weighting evaluation model has emerged as a significant research direction in MCDA and comprehensive evaluation domains (Zhang *et al.* 2024), which is particularly prevalent in engineering applications. Its core mechanism lies in resolving conflicts between different weighting methods through game-theoretic principles to achieve optimsized weight combinations. To overcome the limitations of single-weighting approaches, scholars increasingly employ game theory combined weighting methods to balance decision-makers' subjective preferences with objective indicator data (Fu *et al.* 2022). Notable applications include the following: Tang *et al.* (2024) utilized game-theoretic combined weighting to coordinate four evaluation indicators (safety, flexibility, adaptability, and sufficiency), validating their model's feasibility through cloud computing to support sustainable energy transition. Xie and Hu (2024) developed a game theory combined weighting-TOPSIS method to objectively determine multi-factor impacts on property insurance, establishing practical assessment tools for insurance decision-making. Wang *et al.* (2022) applied this approach to reconcile interests among village collectives, governments, and developers, providing methodological references for urban village renewal evaluations and multi-stakeholder decision scenarios. Within game theory weighting systems, stakeholder preference claims in public decision-making are typically quantified through indicator weight values (Camargo *et al.* 2021). The weight allocation process inherently reflects multi-party interest conflicts and strategic interactions, enabling effective deconstruction of stakeholder demands through this methodology. Furthermore, its application has expanded to cultural creative design (Zhang *et al.* 2022) and product design domains (Zhou *et al.* 2023), demonstrating cross-disciplinary adaptability.

In the weighting system of game theory combined weighting methods (GT-CWM), subjective weighting typically employs the Analytic Hierarchy Process (AHP) (Saaty 2008), while objective weighting utilizes the entropy method. AHP models and quantifies decision-making processes in complex systems through a transparent framework, effectively capturing the core demands of diverse stakeholders (Wang *et al.* 2022). However, practical applications reveal limitations: to satisfy consistency requirements of judgment matrices, original weights often require adjustment, a process that may excessively weaken divergent indicators with significant stakeholder disagreements (Yao *et al.* 2024). In contrast, the entropy method (EWM) calculates information entropy from indicator data to identify measurement dispersion, thereby detecting contentious indicators (Petrov 2022; Wang *et al.* 2013) and assigning them higher weights. Notably, high-divergence indicators identified through entropy analysis frequently suffer from weight reduction in AHP due to consistency correction mechanisms. The integration of these approaches *via* game theory combined weighting establishes a dynamic equilibrium mechanism (Nyimbili and Erden 2020). Such an approach can achieve the dual objectives of an optimized balance of indicator weights and comprehensive accommodation of multi-stakeholder interests. This methodology demonstrates particular efficacy in resolving multi-agent, multi-criteria evaluation challenges. Its application to classroom furniture evaluation holds significant research value and practical relevance, offering systematic solutions for coordinating conflicting demands among stakeholders.

The game theory combined weighting model traditionally employs the Analytic Hierarchy Process (AHP). However, classroom furniture evaluation indicators often exhibit strong subjectivity-metrics such as comfort and aesthetic appeal. These indicators demonstrate significant perceptual variations across stakeholders. In contrast, engineering domains predominantly utilize objective quantifiable indicators such as structural strength and material performance. To mitigate excessive personal bias in AHP-based weight analysis, consensus validation (Kendall and Smith 1939) must be integrated to enhance objectivity and reliability. This approach quantifies expert opinion convergence through Kendall's coefficient of concordance, calibrating individual weights deviating from group consensus to ensure equilibrium in game-theoretic weighting results and improve collective decision-making rigor. Currently, Kendall's concordance coefficient demonstrates broad applicability in complex evaluation scenarios, including healthcare (Wang *et al.* 2023) and land development (Ding *et al.* 2017), proving particularly valuable for resolving multi-stakeholder conflicts in subjective evaluation systems.

In conventional design paradigms, the prioritization of user requirements through weighting methods such as the Analytic Hierarchy Process (AHP) typically enables the derivation of critical design elements to guide practical implementation (Chen and Zhu 2024). However, classroom furniture systems frequently exhibit disconnections between actual configurations and user demands. Sole reliance on user requirements for design development, without validating real-world effectiveness, risks creating ‘satisfaction gaps’ that hinder furniture optimization (Oliver 1997). Therefore, design practice necessitates the integration of current usage patterns with user demands to formulate targeted and actionable optimization strategies. User satisfaction serves as a pivotal metric for evaluating classroom furniture performance (Kapuria *et al.* 2020). Defined as the affective state resulting from comparisons between product performance and user expectations (Li *et al.* 2009), satisfaction levels correlate positively with product efficacy. The fuzzy comprehensive evaluation method (FCE), a widely adopted systematic assessment framework, converts multi-dimensional qualitative evaluations into quantifiable scores, and the approach has been extensively applied in design optimization (Shang *et al.* 2021) and satisfaction measurement (Jin and Xu 2025). To address the accuracy and objectivity limitations of singular evaluation models, this study proposes integrating game theory combined weighting with fuzzy comprehensive evaluation for holistic classroom furniture assessment. Nevertheless, systematic methodologies for analyzing the alignment between furniture configurations and requirements using these dual-dimensional datasets, along with prioritization of improvement targets, remain underexplored and warrant further investigation.

The integration and refinement of these two methodologies for product design guidance would empower designers to establish a closed-loop ‘analysis-evaluation-design’ mechanism. The quadrant diagram model (QDM), by combining indicator importance weights with current satisfaction data, enables precise identification of ‘high-demand-low-adaptation’ conflict points, providing a visual decision matrix for targeted resource allocation and design iteration. Originally proposed by the Leadership Behavior Research Group at Ohio State University as a management theory (Fleishman 1998), the quadrant diagram model (also termed Two-Dimension Theory or Importance-Satisfaction Matrix) serves as a diagnostic framework integrating quantitative and qualitative analysis to investigate correlations between variable pairs (Bi *et al.* 2019). This model visualizes the relationship between user satisfaction levels and expert-assessed importance weights for identical indicators, thereby identifying priority improvement targets with significant configuration-demand mismatches (Wang and Mao 2025). For instance, in urban renewal studies, it has guided spatial optimization by reconciling resident satisfaction with planning priorities (Wang 2015).

In summary, this study aimed to develop a comprehensive and precise evaluation model applicable to quasi-public products. The framework provides a full-cycle solution for classroom furniture design—from demand exploration and current state analysis to targeted design optimization—while its methodological structure holds extensible potential for evaluating other multi-stakeholder quasi-public products, such as medical devices and park facilities. The research employs a composite evaluation model integrating game theory combined weighting, fuzzy comprehensive evaluation, and quadrant diagram analysis. Practical case validation demonstrates the model’s operational feasibility, offering actionable guidance for classroom furniture design enhancement.

DESIGN EVALUATION MODEL FOR MIDDLE-SCHOOL CLASSROOM FURNITURE

The multi-stakeholder collaborative evaluation feedback model developed in this study aims to achieve continuous optimization throughout the classroom furniture design lifecycle (Fig. 1). Its technical framework follows an iterative pathway of 'demand deconstruction→efficacy assessment→design guidance→optimization implementation'. Theoretically, improved solutions can undergo secondary evaluations to establish a closed-loop verification mechanism, while systematically incorporating national policy updates and user feedback as iterative parameters. This paper focuses on model construction from multi-agent collaborative evaluation to design implementation guidance, supported by practical case analyses.

In the demand deconstruction phase, the game-theoretic combination weighting method is employed to allocate weights to multi-stakeholder demands, enabling a rational assessment of each indicator's importance and establishing the 'significance' dimension for subsequent evaluations. In the efficacy evaluation phase, based on the game-theoretic weighting results, the fuzzy comprehensive evaluation method (FUZZY) is utilized to conduct quantitative analysis of user satisfaction, providing a data-driven benchmark for design guidance. In the design guidance phase, through cross-analysis of significance and satisfaction metrics, a visualized priority map is generated to drive targeted resource allocation and inform design implementation.

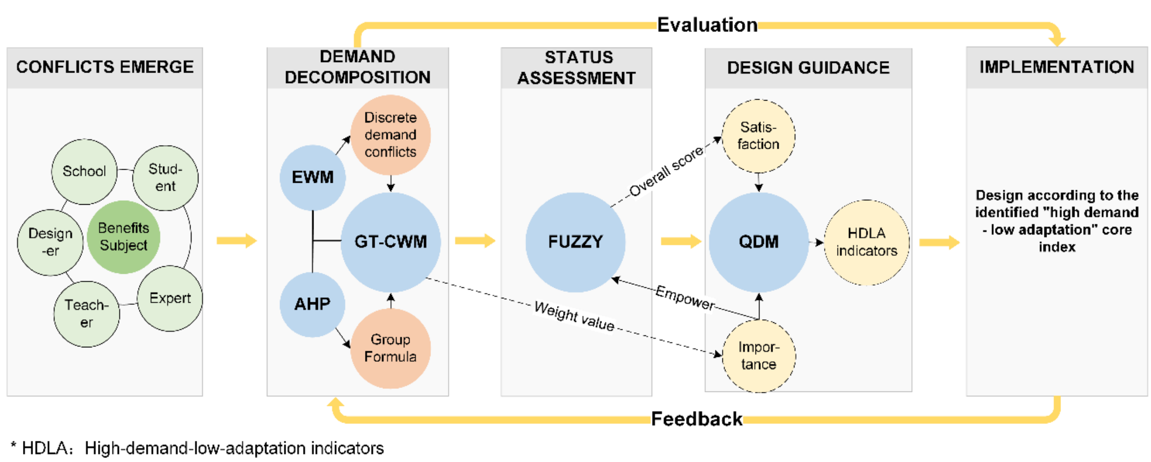

Fig. 1. Design evaluation model for middle-school classroom furniture

Flow chart of middle school classroom furniture design evaluation based on game theory - Fuzzy is shown in Fig. 2. The first step involves establishing the design evaluation indicators for classroom furniture. A comprehensive indicator system is constructed based on the needs of diverse stakeholders and the developmental trends of classroom furniture, with indicators screened by an expert panel to ensure scientific validity and representativeness. Next, the Analytic Hierarchy Process (AHP) captures consensus demands from a collective decision-making perspective, while the Entropy Weight Method identifies conflicting priorities by analyzing objective data divergence. Through game-theoretic equilibrium, the combined weighting approach retains AHP's focus on core demands while enhancing sensitivity to latent conflicts *via* entropy-driven adjustments, ultimately deriving comprehensive weights to assess the relative importance of each indicator. Subsequently, fuzzy linguistic evaluations from users are transformed into multi-level numerical intervals, and satisfaction scores are calculated using membership functions. Finally, the Quadrant Model integrates quantified results into a decision matrix, visually mapping the alignment between classroom furniture configurations and user needs, thereby precisely identifying 'high-importance, low-satisfaction' indicators to guide targeted optimization.

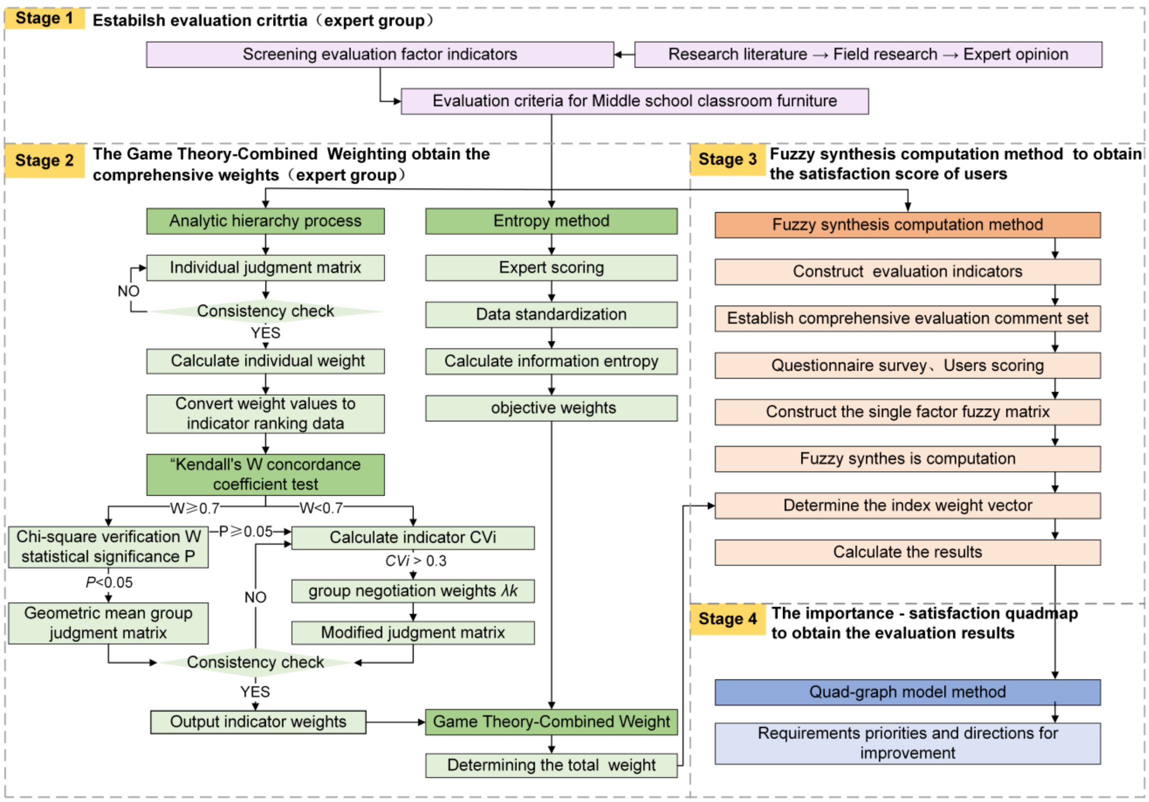

Fig. 2. Flow chart of middle school classroom furniture design evaluation based on game theory - Fuzzy

Establish Evaluation Indicator System

The establishment of the evaluation indicator system must adhere to principles such as objectivity, universality, adaptability, and scalability (Min *et al.* 2000). To guarantee the scientific and representative nature of the indicators, this element set should incorporate the viewpoints of various stakeholders, including students, teachers, school administrators, furniture manufacturers, *etc.*, in order to guarantee the comprehensiveness and practicality of the evaluation system. Students, being the principal users of classroom furniture, place high importance on comfort, functionality, and usability, which are vital elements in furniture design. Teachers, on the other hand, concentrate on durability, ease of cleaning, and the support provided for students' learning behaviors. School administrators stress economic efficiency, maintenance costs, and long-term utility. Manufacturers are preoccupied with production efficiency, cost management, and market competitiveness. As furniture for public education spaces, other factors such as environmental sustainability, safety, and adaptability to diverse teaching requirements also demand attention. Considering the scarcity of research on evaluation systems for secondary school classroom furniture and the absence of standardized guidelines, it is imperative to conduct extensive data collection based on the requirements of students, teachers, administrators, and manufacturers. Subsequently, systematic classification and integration of this data should be performed.

The construction of the evaluation indicator system for middle school classroom furniture followed a sequential approach of ‘literature review → field research → expert consultation → indicator screening’. Initially, key criteria and high-frequency keywords were extracted from national standards such as *Design Code for Primary and Secondary Schools (GB50099 - 2011)* and *Functional Dimensions and Technical Requirements for School Desks and Chairs (GB/T3976 - 2014)*, as well as industry reports including the *2019 Blue Book on the Development of International Schools in China*. Foundational requirements included structural safety, dimensional adaptability (Attai *et al.* 2021), and rational spatial layout. Further refinement incorporated global research literature on ‘classroom space’, ‘school furniture’, and ‘educational furniture’, aligning with contemporary priorities in pedagogical reform and aesthetic design innovation.

Due to the attributes of public goods, the design, application, and management of school homes involve many professional fields such as education and furniture design. In order to consider the diverse needs of different subjects and ensure the universality and comprehensiveness of the indicators, an expert group was set up to classify the information by using the KJ affinity graph method (Xie and Xu 2024), and to screen, supplement, summarise, and cluster the elements of the evaluation indicators. The experts selected 25 cross-disciplinary representatives, including school representatives, faculty members, student groups, designers, and industry experts. The composition of expert group is shown in Table 1. In addition, the authority of the expert group members needed to meet the requirements of $Cr = 0.5\times(Ca + Cs) \geqslant 0.7$ (where Ca is academic authority and Cs is practical experience) (Hsu and Sandford 2007). Among them, Ca refers to the number of papers published in the field of furniture design in the past 5 years, and Cs refers to the number of school furniture projects.

Table. 1. Composition of Expert Group

Expert Groups	Selection Criteria	Cr	Numbers
Teacher	Holds a senior professional title and has been teaching for 10 consecutive years or more, and participation in classroom space renovation projects within the past three	0.72	5
Furniture designer	Leads the completion of at least 3 educational furniture design projects, and the works must have won product design awards at the provincial level or higher.	0.81	5
Student representative	Selects high school students who are required to use the assessment classroom furniture for three consecutive years and rank in the top 30% of their GPA.	0.77	5
School administrator	Holds school-level administrative positions and has more than five years of experience in teaching equipment management.	0.83	5
Furniture expert	The first author has published 3 research papers on classroom furniture design in SCI/SSCI journals.	0.75	5

The classroom furniture evaluation indicator system developed in this study establishes a multidimensional framework integrating five core stakeholders’ divergent demands: students as frequent users prioritize ergonomic comfort; design professionals emphasize full-cycle safety compliance encompassing structural stability (EN 12521) and environmental standards (GB 18580); teaching practitioners focus on pedagogical behavior support metrics; school administrators evaluate asset performance through sustainability, durability, and cost-effectiveness; while educational researchers assess literacy development parameters, particularly educational adaptability. This system translates multi-stakeholder requirements into 25 quantifiable design indicators (Fig. 3), creating an integrated evaluation framework spanning the entire lifecycle from design and production to operation and maintenance, thereby providing actionable guidance for optimizing educational furniture development through evidence-based design validation, manufacturing compliance ($\leqslant$0.124 mg/m^3 formaldehyde emissions), and operational performance monitoring (85% modular components enduring > 5,000 reconfigurations).

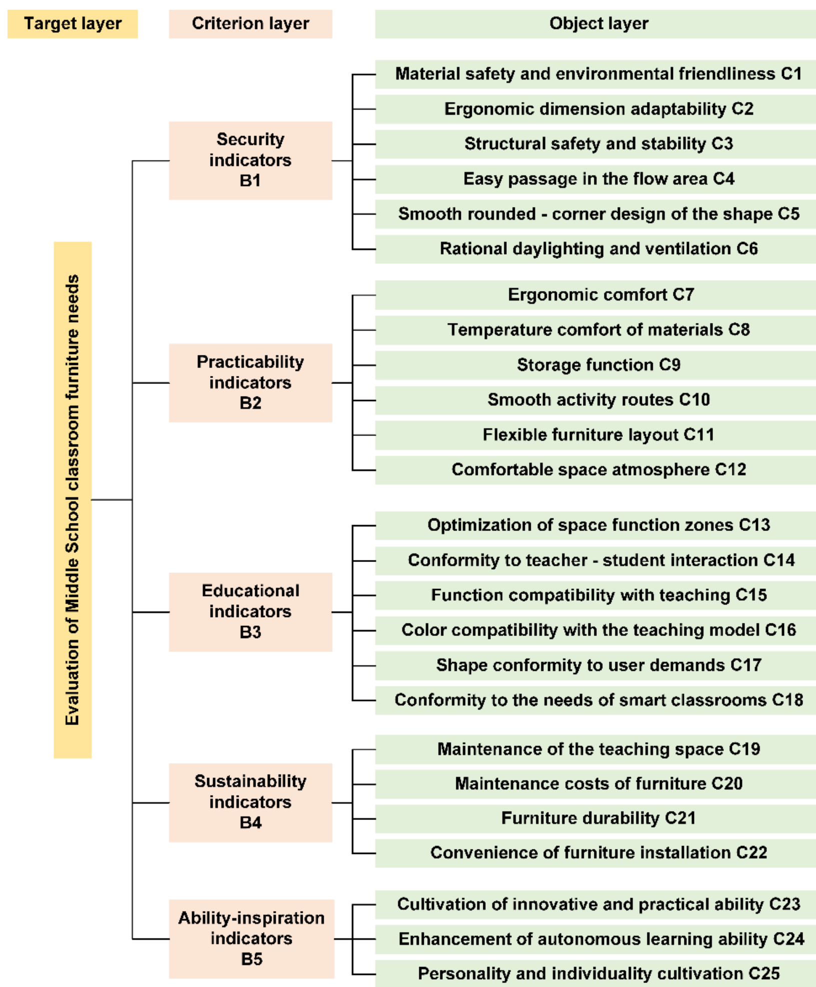

Fig. 3. Classroom furniture evaluation index system

AHP Method to Determine the Subjective Weight of Each Indictor

Given the inherently subjective nature of classroom furniture evaluation indicators, unlike objective metrics in the engineering domain, this study integrated the Kendall concordance coefficient into the fundamental Analytic Hierarchy Process (AHP) framework (Saaty 1980) to mitigate individual biases and enhance the scientific validity and decision-making reliability of evaluation outcomes. The synergistic process involves four phases: (1) group judgment matrix construction, (2) consensus validation (Kendall

1939), (3) feedback-driven adjustment, and (4) comprehensive weight calculation.

Step 1: Individual Judgment Matrix Construction. For *m* decision-makers evaluating *n* indicators at the same hierarchy, pairwise comparisons are conducted. Using the 1–9 scale, each decision-maker *k* constructs a judgment matrix *A(k)* = [*aij(k)*], where $a_{ij}^{(k)}$ denotes the relative importance score of indicator *i* versus *j* by decision-maker *k*. All matrices must pass consistency verification .

Step 2: Consensus Validation. Convert each stakeholder's global weights into demand rankings. Calculate Kendall's concordance coefficient W (Eq. 1) for all decision-makers' indicator rankings, where W,W ∈ [0,1]. Higher W values indicate stronger group consensus (typically requiring W ⩾ 0.7). Validate statistical significance *via* chi-square test (Eq. 2); p < 0.05 confirms meaningful consensus.

Step 3: Feedback Adjustment Mechanism. If the initial Kendall's concordance coefficient W < 0.7, the following feedback mechanisms are triggered. First, Conflict Indicator Identification: Compute rank sums and coefficients of variation $CV_i = \frac{\sigma R_i}{\overline{R_i}}$. Re-evaluate indicators with $CV_i > 0.3$; Second, Dynamic Weight Correction: Introduce group negotiation weights λ_k for disputed indicators, reconstructing composite judgment matrices (Eq. 3).

Step 4: Group Weight Synthesis and Consistency Verification. Calculate final weights *via* eigenvector method (Eq. 4) using adjusted individual matrices. Verify consistency ratio CR (Eq. 5); iterations return to Step 3 if CR ⩾ 0.1.

$$S = \sum_{i=1}^{n}\left(R_i - \overline{R}\right)^2 \quad , \quad R_i = \sum_{k=1}^{m} \lambda_k . rank\left(\omega_i^k\right)$$

$$\overline{R} = \frac{m(n+1)}{2}, \quad W = \frac{12S}{m^2(n^3-n)} \tag{1}$$

where the rank sum R_i of indicator *i* is the total of ranking values assigned by all decision-makers.

$$X^2 = \mathrm{m}(\mathrm{n}-1)W \tag{2}$$

$$\mathrm{a_{ij}}^{综合} = \prod_{k=1}^{m} \mathrm{a}_{ij}^{(k)^{\lambda_k}}, \quad \sum \lambda_k = 1 \tag{3}$$

$$A^{综合} \bullet \omega = \lambda_{max} \cdot \omega \tag{4}$$

where λ_{max} is the maximum eigenvalue and ω is the normalised weight vector.

$$CI = \frac{\lambda_{max}-n}{n-1}, \quad CR = \frac{CI}{RI} \tag{5}$$

Entropy Method to Determine the Objective Weight

This study employs the entropy method for objective weighting, leveraging information entropy theory to quantify the dispersion of multi-stakeholder evaluation data, thereby effectively identifying demand divergences among stakeholders. The entropy method transforms opinion heterogeneity into mathematical representations, thereby providing an objective basis for subsequent game-theoretic weighting through quantified discrepancy analysis. The implementation process comprises four phases: (1) multi-source data matrix construction (Eq. 6) to systematically integrate heterogeneous opinions; (2) data standardization using the range method (Eq. 7) to eliminate dimensional differences, yielding a normalized matrix Y = (yij)m × n within the [0, 1] interval (Here, j is the evaluation indicator number, i represents the respondent's ID. Yij is the normalized value of the i-th respondent for the j-th indicator, Xij is the raw data value of the i-th respondent for the j-th indicator, (Xij)_min is the minimum value of the j-th indicator in the raw data, and (Xj)_max and (Xj)_min are the maximum and minimum values of the j-th indicator, respectively.); (3) entropy-based divergence quantification (Eq. 8) where entropy values ej ∈ [0, 1) reflect group opinion dispersion; and (4) divergence-driven weight calculation (Eq. 9), prioritizing indicators with higher stakeholder conflicts. This methodology bridges subjective preferences with mathematical rigor, enabling adaptive weight optimization across design iterations.

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \tag{6}$$

$$Y_{ij} = \frac{X_{ij} - (X_{ij})_{min}}{(X_j)_{max} - (X_j)_{min}} \tag{7}$$

$$P_{ij} = \frac{1 + Y_{ij}}{\sum_{j=1}^{n} Y_{ij}} \tag{8}$$

$$e_j = -\frac{1}{Inn}\left(\sum_{i=1}^{n} P_{ij} In P_{ij}\right), W_i = \frac{1 - e_j}{m - \sum_{j=1}^{m} e_j} \tag{9}$$

Game-Theory Combination of Weights to Obtain the Overall Weights

This study introduces a game-theoretic combined weighting method that harmonizes conflicts between subjective and objective weights, achieving optimal retention of both information types while minimizing their discrepancies. The core lies in constructing a game equilibrium between subjective and objective weights through the following implementation pathway: (1) Base Weight Generation – Determine initial weights for n indicators *via* linear combinations (Eq. 10); (2) Objective Function Formulation – Minimize comprehensive deviations between combined weights and original weights (Eq. 11); (3) Matrix Differentiation – Derive optimal first-order derivative conditions (Eq. 12) and linear equation systems (Eq. 13); (4) Coefficient Optimization – Normalize absolute combination coefficients (Eq. 14); and (5) Weight Synthesis – Generate equilibrium weights through Nash bargaining solutions (Eq. 15).

$$\boldsymbol{w}_l = (w_{l1}, w_{l2}, \cdots, w_{ln}), l = 1,2, \cdots, L \tag{10}$$

$$\boldsymbol{w} = \sum_{l=1}^{L} \alpha_l \boldsymbol{w}_l^T \ (\alpha_l > 0) \quad (10)$$

where w represents the combined weight vector, and α_l represents the linear combination coefficient.

$$\min \left\| \sum_{l=1}^{L} \alpha_l \boldsymbol{w}_l^T - \boldsymbol{w}_p^T \right\|_2, p = 1,2, \cdots, L \tag{11}$$

$$\sum_{l=1}^{L} \alpha_l \boldsymbol{w}_p \boldsymbol{w}_l^T = \boldsymbol{w}_p \boldsymbol{w}_p^T, p = 1,2, \cdots, L \tag{12}$$

$$\begin{bmatrix} \boldsymbol{w}_1\boldsymbol{w}_1^T & \boldsymbol{w}_1\boldsymbol{w}_2^T & \cdots & \boldsymbol{w}_1\boldsymbol{w}_L^T \\ \boldsymbol{w}_2\boldsymbol{w}_1^T & \boldsymbol{w}_2\boldsymbol{w}_2^T & \cdots & \boldsymbol{w}_2\boldsymbol{w}_L^T \\ \vdots & \vdots & \vdots & \vdots \\ \boldsymbol{w}_L\boldsymbol{w}_1^T & \boldsymbol{w}_L\boldsymbol{w}_2^T & \cdots & \boldsymbol{w}_L\boldsymbol{w}_L^T \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_L \end{bmatrix} = \begin{bmatrix} \boldsymbol{w}_1\boldsymbol{w}_1^T \\ \boldsymbol{w}_2\boldsymbol{w}_2^T \\ \vdots \\ \boldsymbol{w}_L\boldsymbol{w}_L^T \end{bmatrix} \tag{13}$$

$$\alpha_l^* = |\alpha_l| / \sum_{l=1}^{L} |\alpha_l| \tag{14}$$

$$\boldsymbol{w}^* = \sum_{l=1}^{L} \alpha_l^* \boldsymbol{w}_l^T, l = 1,2,\cdots,L \tag{15}$$

Fuzzy Method to Determine the Satisfaction Evaluation

The fuzzy comprehensive evaluation method is introduced to establish a satisfaction analysis framework through the following integrated workflow: Initially, the evaluation indicator system is defined by synthesizing hierarchical criteria (as depicted in Fig. 3), followed by the establishment of a five-level evaluation grade set M = {M1, M2, M3, M4, M5}, where M1-M5 represent evaluation levels from 1 to 5. After assigning values, the intervals for M1-M5 are as follows: (0, 20], (20, 40], (40, 60], (60, 80], and (80, 100]. Expert assessments are then conducted on secondary indicators to construct single-factor Fuzzy evaluation matrices D (Eq.16), where each element Kij represents the membership degree of indicator ii to grade j. Leveraging criterion-layer weights derived from game-theoretic combination weighting (WB, WB1, WB2, WB3, WB4 ,WB5), the fuzzy comprehensive vector P is computed *via* P = W × D (Eq. 17). Finally, normalization is applied to P using maximum-value scaling (Eq. 18), and the composite satisfaction score T is calculated by weighting normalized values against predefined grade benchmarks.

$$D = \begin{bmatrix} K_{11} & \cdots & K_{1n} \\ \vdots & & \vdots \\ K_{m1} & \cdots & K_{mn} \end{bmatrix} \tag{16}$$

$$P = W \times D = (WB_1, WB_2, WB_3, WB_4, WB_5) \times \begin{bmatrix} K_{11} & \cdots & K_{1n} \\ \vdots & & \vdots \\ K_{m1} & \cdots & K_{mn} \end{bmatrix} = (f'_1, f'_2, \ldots f'_n) \tag{17}$$

$$P' = \frac{P}{\sum_{j=1}^{n} f'_j}, T = P_1 \times \theta \tag{18}$$

The Quad-Graph Model to Determine the Importance-Satisfaction Evaluation Matrix

This study incorporates the quadrant diagram model (Fleishman 1998) to establish a dual-dimensional evaluation mechanism. On one hand, it mitigates decision bias inherent in traditional single-dimensional assessments by integrating both importance weights and satisfaction scores into a unified evaluation matrix, forming a comprehensive analytical framework. On the other hand, leveraging the model's partitioning capability, indicators are categorized into four quadrants, enabling precise identification of 'high-priority-low-performance' critical optimization targets.

The quadrant diagram model categorizes indicators into four distinct zones within the coordinate space (Fig. 4): Advantage Zone, Maintenance Zone, Opportunity Zone, and Improvement Zone. The Improvement Zone (high importance - low satisfaction) represents critical user pain points with significant gaps between current configurations and user expectations, necessitating prioritized optimization efforts. The Advantage Zone (high importance - high satisfaction) embodies core competitive strengths that require sustained technological innovation and user experience refinement to maintain leadership. The Opportunity Zone (low importance - low satisfaction) serves as a potential incubator for latent demands, where uncovering hidden value can drive new growth opportunities. The Maintenance Zone (low importance - high satisfaction) balances resource efficiency by preserving existing performance while proactively mitigating quality risks. This quadrant-based prioritization framework systematically guides strategic resource allocation and action planning, offering a data-driven roadmap for design innovation and iterative enhancement.

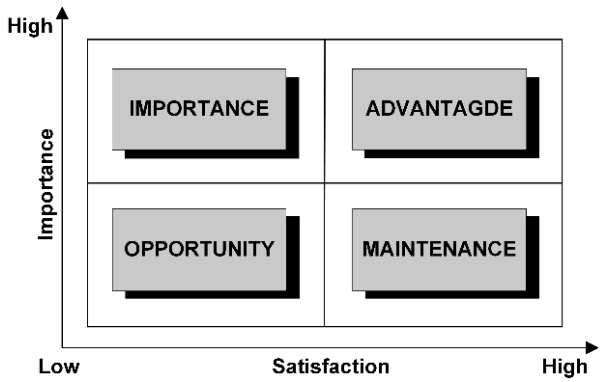

Fig. 4. Quadrant diagram model

APPLICATION EXAMPLE OF EVALUATION MODEL

To verify the rationality and feasibility of the evaluation model for middle school classroom furniture based on the Game Theory Combined Weighting, the Fuzzy Method, an empirical test of the indicator system and evaluation model, was carried out with M Middle School as a case study. This empirical test also aimed to evaluate the development level of classroom space and furniture in M Middle School (Shao 2024). Established in 1923 and situated in Eastern China, M Middle School has a long-standing history of construction and development. This history reflects the changes in the design and standards of secondary education buildings within China. Moreover, in terms of furniture configuration, spatial arrangement, and educational standards, this school shares similar characteristics with numerous schools across the country, thereby making it a representative case. The school consists of a total of 142 classrooms, which are distributed among three academic buildings. Table 3 presents the basic attributes and characteristics of the general classroom spaces in this middle school.

To ensure case representativeness and typicality, M Middle School was validated across five dimensions-basic attributes, operational management, hardware facilities and teaching environments, student characteristics, policies, and external contexts—as detailed in Table 2. The study employed a one-sample t-test (Cohen 1988) to systematically assess its typicality in different dimensions, with all indicators passing significance verification ($\alpha = 0.05$). Data collection came from official statistics (National Compulsory Education Quality Monitoring Reports, Jiangsu Provincial Education Department Annual Reports, school asset registries), field measurements (classroom parameters captured *via* laser rangefinders (Takona 2024), and illuminance meters with ±1% error control), and standardized surveys (student anthropometrics aligned with the *National Student Physical Health Standards*). Continuous variables underwent Z-score normalization ($Z = \frac{X-\mu}{\sigma}$, where μ is the regional mean and σ is the standard deviation) (Field 2013) to eliminate dimensional heterogeneity, ensuring cross-indicator comparability in multi-criteria analysis.

Table 2. Comparison Verification Table for M School

Angle	Sub-dimension	M Standard	Local Standard	National Standard	t-test Result
School Scale	Class Size	48 students	50 students	≤55 students	*t*=4.33,*p*<0.0019
	Student size	2,969	≤3,000	≤3,000	*t*=9.25,*p*<0.001
Funding Manag-ement	Curriculum Structure	85% Core + 15% Elective	75% (σ=3%*σ*=3%)	Core ≥70%	*t*=13.33,*p*<0.001
	Teaching staff	38%	28% (σ=4%)	20%	*t*=12.50,*p*<0.001
	Per Capita Education Funding	¥19,200	¥17,000 (σ=±1,200)	≥¥12,000	*t*=9.17,*p*<0.0019
Hard-ware facility	Service life	5 years	6.5 years2	8 years	*t*=8.44,*p*<0.0019
	Price Compliance	Regional Bid Price ±8%	Allow ±10%	Allow ±15%	*t*=2.50,*p*=0.015
	Material Safety	GB 28007	95% pass	GB 28007	Chi-square test
	Structural Safety	Seismic Level 8	Requires Level 7	National Standard Level 7	compliance
Student analysis	Body Characteristics	Male: 174 cm Female: 160 cm	170 cm (σ=2)	National Standard P50 Curve	*t*=10.00,*p*<0.001
	Gender Ratio	Male 53%	51% (σ=0.5%)	45%-55%2	*t*=4.00,*p*<0.001
Policy Support	Policy Preference	Special Fund+15%	Mean +5% (σ=8%)	Local standards	*t=3.92, p<0.001*

By quantitatively comparing the key indicators, it provides a comprehensive reflection of the typicality and compliance of M in terms of educational resources, construction conditions, and student characteristics, making it suitable for feasibility and applicability analysis of the model as a case study. The current status of teaching spaces and furniture in M is shown in Table 3.

Table 3. The Current State of the Classroom Space

Size	Per capita area	Furniture design	Technical facilities	Photo
48	1.56m^2 /person	Single-seat Single-desk locker podium Microphone	Whiteboard radio projector computer	

AHP Method to Determine the Subjective Weight of Each Indictor

A judgment matrix was established based on the classroom furniture evaluation indicator system. An expert panel, as detailed in Table 1, was enlisted to jointly evaluate the significance and weights of each evaluation criterion for middle-school classroom furniture through the application of a 9-point scale. Based on the final scores derived from the decision-making procedure, a judgment matrix was formulated. This matrix successfully passes the consistency test, thereby guaranteeing that the calculated weights are in harmony.

The experimental methodology employed structured questionnaires administered in soundproof meeting rooms, where experts individually completed paper-based surveys under controlled 30-minute time limits using digital timers to mitigate group pressure interference. The questionnaire comprised two sections: the first collected demographic data (gender, age, profession, educational background) to analyze potential biases in group decision-making, while the second contained 25 indicator-specific subjective evaluation items for classroom furniture. Each indicator was accompanied by contextualized case examples and regulatory references.

Two iterative consensus validations were conducted: the initial round yielded a Kendall's $W = 0.62$ ($p < 0.01$), while the second achieved $W = 0.79$ ($p<0.001$), satisfying the high-consensus threshold ($W\geq0.7$) for social science research. This statistically significant progression confirmed expert consensus. Finally, the geometric mean method synthesized group judgment matrices, passing consistency verification ($CR<0.1$) to derive weights for middle school classroom furniture. The weights of AHP method is shown in Table 4.

Table 4. Weights of AHP Method

Criterion Layer		Subcriteria Layer			Total Weight Value	Ranking
Index	Weight	Index	Weight	CR		
B1	0.395	C1	0.275	0.006<0.1	0.109	1
		C2	0.134		0.053	5
		C3	0.256		0.101	2
		C4	0.075		0.029	9
		C5	0.134		0.053	4
		C6	0.127		0.050	6
B2	0.239	C7	0.362	0.011<0.1	0.087	3
		C8	0.084		0.020	17
		C9	0.133		0.032	10
		C10	0.075		0.018	18
		C11	0.228		0.055	8
		C12	0.119		0.028	11
B3	0.173	C13	0.314	0.017<0.1	0.054	7
		C14	0.176		0.030	11
		C15	0.176		0.030	15
		C16	0.062		0.011	24
		C17	0.108		0.019	21
		C18	0.165		0.029	16
B4	0.120	C19	0.351	0.004<0.1	0.042	14
		C20	0.351		0.042	13
		C21	0.189		0.023	18
		C22	0.109		0.013	22
B5	0.073	C23	0.334	0.052<0.1	0.024	19
		C24	0.142		0.010	25
		C25	0.275		0.038	20

Entropy Method to Determine the Objective Weight

In this study, the questionnaire method was used. The expert group was provided with a soundproof conference room, a paper questionnaire, and a timer (limited time of 30 minutes/person) to avoid cross interference. Based on the empirical study conclusions of Leatham (2002) (the 5-level scale achieved the optimal balance between cognitive load and discrimination), 25 indicators were scored by 5-level Likert scale, and the options were set as (very important=5, important=4, neutral=3, not important=2, very unimportant=1). The questionnaire consisted of two parts: the first part was the basic information of experts, including gender, age, occupation, and education background; The second part was the importance score table set according to 25 indicators (Table 2) of classroom furniture in middle school. In order to ensure that the perspective and basis of data collection were consistent under different evaluation methods and to avoid the deviation of results caused by differences in expert groups, 25 members in Table 1 were still selected as the subjects of questionnaire distribution.

The entropy weight method questionnaire collected 25 valid responses, with a Cronbach's alpha of 0.768 (>0.7 threshold), confirming its validity. Following the entropy weight method's computational procedures, objective weight results were derived. The weights of Entropy method is shown in Table 5.

Table 5. Weights of Entropy Method

Criterion Layer		Subcriteria Layer		Total Weight Value	Ranking
Index	Weight	Index	Weight		
B1	0.262	C1	0.156	0.041	10
		C2	0.122	0.032	16
		C3	0.194	0.051	7
		C4	0.144	0.038	12
		C5	0.236	0.062	3
		C6	0.148	0.039	11
B2	0.178	C7	0.153	0.027	20
		C8	0.141	0.025	21
		C9	0.181	0.032	16
		C10	0.260	0.046	9
		C11	0.107	0.019	23
		C12	0.158	0.028	19
B3	0.282	C13	0.064	0.018	25
		C14	0.212	0.060	4
		C15	0.254	0.072	2
		C16	0.191	0.054	6
		C17	0.166	0.047	8
		C18	0.113	0.032	16
B4	0.144	C19	0.132	0.019	23
		C20	0.243	0.035	14
		C21	0.396	0.057	5
		C22	0.229	0.033	15
B5	0.135	C23	0.548	0.074	1
		C24	0.267	0.036	13
		C25	0.185	0.025	21

Game-Theory Combination of Weights to Obtain the Overall Weights

Based on the subjective and objective weights of each indicator, the subjective and objective combination coefficients were 0.656 and 0.344 respectively, using the combination principle of game theory. Subsequently, the combined weight values of the evaluation indicators for middle school classroom furniture were derived according to the calculation steps, as shown in Table 6.

Table 6. Summary of Game Theory Comprehensive Weights

Criterion Layer		Subcriteria Layer		Total Weight Value	Ranking
Index	Weight	Index	Weight		
B1	0.350	C1	0.245	0.086	1
		C2	0.131	0.046	6
		C3	0.239	0.084	2
		C4	0.092	0.032	16
		C5	0.160	0.056	4
		C6	0.132	0.046	5
B2	0.218	C7	0.304	0.066	3
		C8	0.100	0.022	23
		C9	0.147	0.032	17
		C10	0.127	0.028	21
		C11	0.195	0.043	8
		C12	0.128	0.028	20
B3	0.211	C13	0.197	0.042	9
		C14	0.191	0.040	11
		C15	0.211	0.044	7
		C16	0.122	0.026	22
		C17	0.136	0.029	19
		C18	0.142	0.030	18
B4	0.128	C19	0.266	0.034	14
		C20	0.309	0.040	12
		C21	0.271	0.035	13
		C22	0.155	0.020	24
B5	0.094	C23	0.438	0.041	10
		C24	0.202	0.019	25
		C25	0.357	0.034	15

Figure 5 shows the weight result curves based on the three weighting methods. In the Analytic Hierarchy Process (AHP), the safety index (B1) dominated with a significant weight of 0.395, which is in line with the industry/national standards (GB/T 3976-2014, GB 50099-2011) and also reflects the core demands of multiple entities. In the Entropy Method, the weight of the educational index (B3) reached 0.282, and its dispersion coefficient was much higher than that of the safety index, reflecting the demand differences of multiple entities.

The transformation of the educational mode put forward higher requirements for the teaching space and furniture facilities. Therefore, teachers and industry experts pay special attention to the educational index. In order to maintain the importance of the safety index and take into account the educational needs, the game theory combined weight method based on the theory of minimizing differences and achieving equilibrium was adopted, and the obtained weight result lay between the results of the Analytic Hierarchy Process and the Entropy Method. This method can effectively balance the weights of various indicators and also take into account the needs of all stakeholders, thus obtaining a more scientific and reasonable weighting result. Through this result, the effectiveness of the game theory combined weight method in achieving the balance of multiple parties' demands in the furniture field is further verified, providing a reference for the importance evaluation of the evaluation index system of classroom furniture.

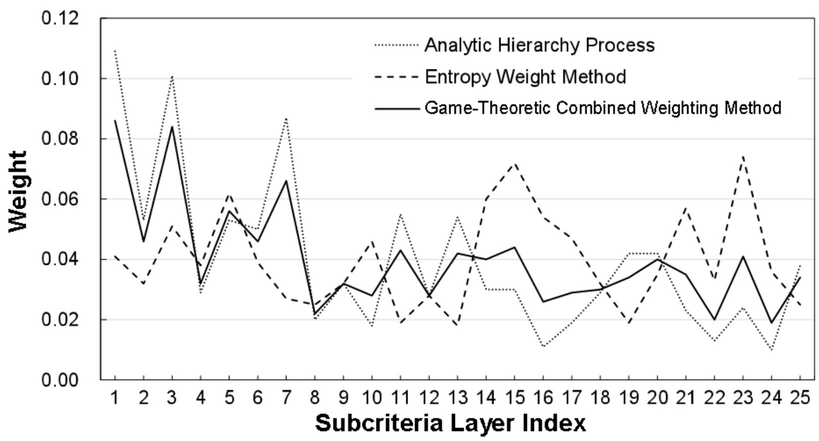

Fig. 5. Result curve chart of the weights for each method

Fuzzy Method to Determine the Satisfaction Evaluation

After determining the comprehensive weights of each indicator, the Fuzzy Comprehensive Evaluation Method was applied to evaluate the satisfaction of the use of classroom furniture in M Middle School, so as to obtain the current construction situation of the classroom furniture.

Table 7. Fuzzy Comprehensive Evaluation Results

Target Layer		Criterion Layer			Subcriteria Layer		Ranking
Score	Ranking	Index	Score	Ranking	Index	Score	
65.40	4	B1	70.39	4	C1	68.8	4
					C2	64	4
					C3	79.8	4
					C4	63.2	4
					C5	70.4	4
					C6	75.2	4
		B2	60.15	4	C7	58.4	3
					C8	63.2	4
					C9	59.6	3
					C10	61.6	4
					C11	60.8	4
					C12	59.2	3
		B3	58.84	3	C13	60.8	4
					C14	59.2	3
					C15	58.4	3
					C16	56	3
					C17	57.6	3
					C18	62.4	4
		B4	62.23	4	C19	66.4	4
					C20	61.6	4
					C21	69.6	4
					C22	62.4	4
		B5	52.85	3	C23	52.8	3
					C24	49.6	3
					C25	55.2	3

In this study, the questionnaire survey method was adopted. To make the data more authentic and reliable, the survey subjects were selected as 125 students and 25 middle school teachers in M Middle School, covering different grades and subject backgrounds. During the students' evening self-study period, permission was obtained to enter the classes and distribute the questionnaires.

The questionnaire used the Likert five-point scale to score the satisfaction of 25 indicators. A total of 150 valid questionnaires were retrieved from the questionnaire survey using the Fuzzy Comprehensive Evaluation Method. The Cronbach's alpha value of the questionnaire validity is 0.875 > 0.8, indicating that the questionnaire is valid. The analysis results of the Fuzzy Comprehensive Evaluation Method are shown in Table 7.

According to the calculation and analysis of the questionnaire data, the evaluation result of the classroom furniture in M Middle School was 65.40, which is at the fourth level, basically taking into account the importance of safety, comfort, and education. Among them, safety (B1), comfort (B2), and sustainability (B4) all reached the fourth level, while education (B3) and ability inspiration (B5) failed to reach this level, resulting in a relatively low comprehensive score. This also reflects that the current design of classroom furniture in M Middle School did not match the actual educational needs. The on-site investigation reveals that, on the one hand, there is an imbalance in the budget allocation of the school. Non-core indicators (lockers) occupy too much renovation funds, leading to a lag in the upgrading of key teaching equipment. At the same time, the furniture layout in M Middle School is rigid. Fixed desks, chairs, and podiums account for a large proportion, restricting the interaction between teachers and students and being unable to support students' independent exploration and collaborative innovation. On the other hand, only 12% of the classrooms in the school are equipped with collaborative furniture, and it takes up to 15 minutes to rearrange the furniture, making it impossible to carry out effective group discussions.

The Quad-Graph Model to Determine the Importance-Satisfaction Evaluation Matrix

In order to accurately locate the priority improvement items, the Quadrant Chart Model was adopted. Taking the satisfaction index value as the horizontal axis and the importance satisfaction value as the vertical axis, and using the average value as the critical line of the horizontal and vertical axes, a scatter plot of 'importance – satisfaction' of classroom furniture in M Middle School was drawn in the four quadrants. The evaluation results of the Four-Quadrant Diagram for Classroom Furniture is shown in Fig. 6. The 25 core indicators were positioned in four strategic areas to achieve the visual output of demand characteristics.

As can be seen from the figure, the 25 evaluation indicators were distributed among all four quadrants. Among them, the advantage area (high importance - high satisfaction) included four indicators, namely C1, C3, C5 and C6, indicating that these functions currently possess core competitiveness. It is advisable to maintain this level, and there is no need to allocate excessive resources to them.

The opportunity area (low satisfaction - low importance) had the largest concentration, with a total of 13 indicators. This shows that non-core indicators account for a relatively large proportion in the design decision-making process, and these features have not attracted the attention of users. Therefore, within the scope permitted by resources, it is possible to appropriately explore the implicit value of this area. The maintenance area (low importance - high satisfaction) includes two functional indicators, C19 and C21.

However, it is worth noting that the indicators in the low importance area are not static. It is necessary to consider whether the update of national standards and other factors will affect their weights, so as to adjust the priority order in a timely manner. The improvement area (high importance - low satisfaction) includes six indicators: ergonomic dimension adaptability (C2), ergonomic comfort (C7), functionality's fit with teaching methods (C15), flexibility of spatial layout (C11), optimization of spatial functional areas (C13), and cultivation of innovative practical ability (C23). These indicators reflect the pain points existing in the current classroom furniture and should be regarded as the primary breakthrough points for design optimization.

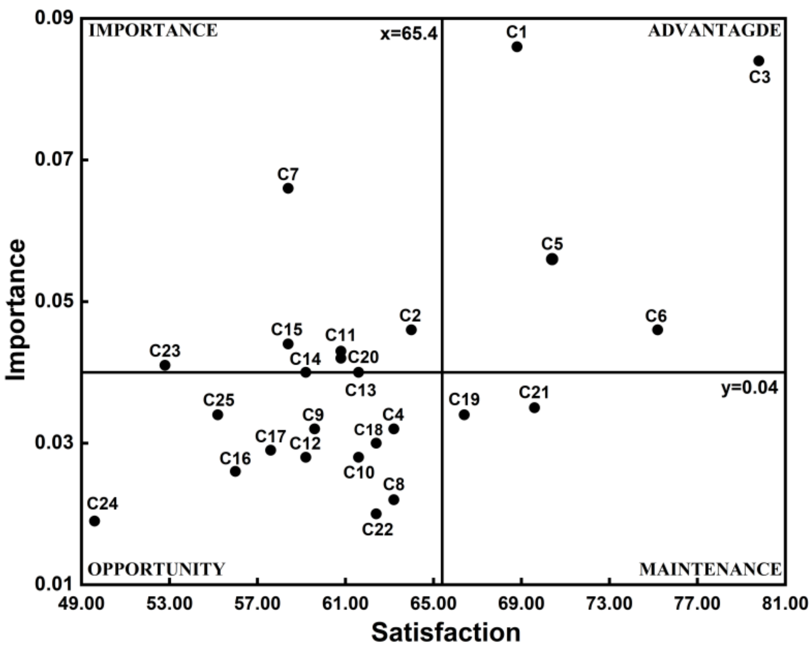

Fig. 6. Evaluation results of the Four-Quadrant diagram for classroom furniture

DISCUSSION

Through the collaborative analysis of the Analytic Hierarchy Process (AHP) and the Entropy Method, this study revealed deep-seated contradictions between the demand consensus (Table 5) and the divergence (Table 6) in the evaluation of classroom furniture. As discovered from Fig. 5, there were significant differences in the educational indicators between the two weighting methods. The AHP weight (0.173) reflects the basic consensus of the group on the teaching adaptability, while the high dispersion coefficient (0.282) of the Entropy Method exposes the cognitive conflicts of multiple entities regarding the connotation of 'educational empowerment'. As Kariippanon *et al.* (2020) pointed out, teachers still regard the traditional layout and furniture as their comfort zone; while designers and school leaders will emphasize the transformation of classroom furniture, leaving teachers with no choice. This phenomenon reflects the practical dilemma of China's educational reform (Su 2020). Although the 'student-centered' teaching model has been implemented for many years, the design of classroom furniture is still limited by the traditional 'lecture-style' spatial paradigm. The reasons are as follows. On the one hand, the current classroom furniture standards (such as GB/T 3976-2014) do not include education as a mandatory indicator. On the other hand, the market lacks furniture products that match the actual needs (Chen *et al.* 2024) Based on the coupled analysis of the combined weighting based on game theory and the Fuzzy Comprehensive Evaluation (Tables 6-7), the satisfaction ranking (4/5) of the educational indicators is lower than the comprehensive weight ranking (3/5), reflecting the mismatch between the 'configuration of classroom furniture and teaching needs'(Echeverria 2018). The Quadrant Chart Model further locates the educational and other related indicators in the improvement area of 'high demand - low adaptability'. The discussion in this section, taking education as a breakthrough point, once again confirms the scientificity and adaptability of this composite model in solving the evaluation problem of the diverse needs of classroom furniture. In addition, it can also be extended to the field of quasi-public goods.

Improvement Area Indicators Should Be Met First

The indicators in the improvement area of 'high demand - low adaptability' include C2, C7, C15, C11, C13, and C23, which need to be prioritized for breakthrough in the design optimization of middle school classroom furniture. Among them, C2 and C7 are the continuous focuses in the field of school furniture design and belong to the category of basic human factors needs, which is consistent with the view proposed by Smith (2007) that the satisfaction of human factors needs is a mandatory prerequisite for the design of educational furniture. In order to improve the adaptability of the furniture, a multi-dimensional adjustment mechanism and an intelligent adaptation extension system can be explored, and intelligent furniture that can sense students' body postures and environmental parameters can be developed, such as monitoring sitting postures through pressure sensors. To enhance users' comfort, in-depth exploration can be carried out in aspects such as the support design of the contact surface materials and temperature control. C15, C13, and C11 are all fall within the category of teaching scene responsive design. They need to be adapted to teaching needs and are also the key directions for future design, which is in line with the priority of future classroom furniture design in the research of Zhou and Chen (2023). The teaching functions of the furniture should be deeply developed. For example, the classroom space layout and furniture should achieve decentralized movement on demand (Jing *et al.* 2025), providing support for users to carry out social interactions and switch teaching modes at any time for learning. C23 is the design goal of middle school classroom furniture. This goal can be achieved by building a learning pathway (to facilitate the input and construction of new knowledge) and a learning exhibition area (to facilitate the output and evaluation of new knowledge) (Jin and Shen 2024). Among them, the learning pathway includes wireless microphones, collaboration software, metaverse platforms, *etc.*; the learning exhibition area includes 360-degree writable whiteboards, wireless presentation, eye-tracking student learning technology, *etc*.

CONCLUSIONS

1. Aiming at the problem of the mismatch between the diverse needs of classroom furniture and the actual configuration, this study has constructed a composite evaluation model of 'Game Theory Combined Weighting - Fuzzy Comprehensive Evaluation Method - Quadrant Chart Model', and formed a four-level evaluation path of 'demand deconstruction-current situation evaluation-design guidance-optimization implementation'. Through the game weighting of the improved Analytic Hierarchy

Process (AHP) and the Entropy Method, the demands of multiple entities such as teachers and students were effectively balanced. Based on the Fuzzy Comprehensive Evaluation Method, the user satisfaction was quantified, and the current configuration situation was accurately depicted. The Quadrant Chart Model conducts a cross-analysis of weights and satisfaction, locates the core of the contradiction of 'high demand - low adaptability', and drives the precise allocation of resources. This model can provide a reference for companies engaged in the design and development of classroom furniture, and it can also be extended to the design evaluation fields of quasi-public products involving multiple entities, such as public medical products and park facilities.

2. This study used the composite evaluation model to conduct an empirical test on the supply-demand adaptability of middle school classroom furniture, taking the classroom furniture of M Middle School as a case. The results show that after the game weighting, the weight of the educational index was calibrated to 0.211, effectively balancing the demand conflicts of multiple entities. The comprehensive evaluation of M Middle School is at the fourth level, and the satisfaction of the educational index is relatively low, which is consistent with the situation of the on-site investigation. The Quadrant Chart accurately identifies six indicators of 'high demand - low adaptability', which are consistent with the key optimization directions of the current classroom furniture, confirming the feasibility and accuracy of the model in solving the contradiction between diverse needs and actual configurations.
3. The future directions of middle school classroom furniture include ergonomic dimension adaptability, ergonomic comfort, functionality's fit with teaching methods, flexibility of spatial layout, optimization of spatial functional areas, and cultivation of innovative practical ability. These reflect the existing pain points of the current classroom furniture and should be regarded as the primary breakthrough points for design optimization.
4. This paper is limited to the construction and verification of the theoretical model. Due to the limited space, the work of the closed loop and design verification will be reported in full in another paper in the future.

REFERENCES CITED

Attai, S. L., Reyes, J. C., Davis, J. L., York, J., Ranney, K., and Hyde, T. W. (2021). "Investigating the impact of flexible furniture in the elementary classroom," *Learning Environments Research* 24(2), 153-167. DOI: 10.1007/s10984-020-09322-1

Camargo, M., Palominos, P., Marche, B., Toledo, F., Boly, V., and Alfaro, M. (2021). "A multi-stakeholder system-based methodology to evaluate the needs of innovation ecosystems," *Res. Eng. Design* 32(4), 489-506. DOI: 10.1007/s00163-021-00368-7

Chen, Y., Ren, Z., Hu, B., and Zheng, H. (2023). "Investigation of the critical factors influencing multi-stakeholders' participation in design optimization of EPC projects," *Buildings* 13(7), article 1654. DOI: 10.3390/buildings13071654

Chen, G. X., and Zhu, J. G. (2024). "Design of small family intelligent furniture based on KANO model and fuzzy comprehensive evaluation," *J. Forestry Eng.* DOI: 10.13360/j.issn.2096-1359.202408004

Chen, R., Ke, Q., Yao, X. C., Zhang, Y. M., and Yang, S. Y. (2024). "Research on innovative design of smart classroom furniture under participatory teaching," *Furniture* 45(04), 54-59. DOI:10.16610/j.cnki.jiaju.2024.04.012

Chen, S. P., Liu, Z. H., Yao, Z. Z., Qian, Y. X., and Zhang, Z. J. (2025). "Research on the promotion of intelligent diagnosis and treatment service based on the tripartite evol utionary game," *J. Modern Inform.* http://kns.cnki.net/kcms/detail/22.1182.G3.2025 0214.1547.004.html

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*, Routledge, London. DOI:10.4324/9780203771587

Ding, X. X., Wu, J., and Jin, L. M. (2017). "Evaluation of development suitability of low hill gentle slope based on Kendall union coefficient," *Bengbu Univ.* 6(04), 31-35+68. DOI: 10.13900/j.cnki.jbc.2017.04.007

Echeverria, N. (2018). "Pedagogy as a fundamental part of school furniture design," in: *Handbook of Research on Ergonomics and Product Design*, Springer, Singapore. DOI:10.4018/978-1-5225-5234-5.ch006

Field, A. (2013). "Discovering Statistics using IBM SPSS Statistics," Sage Publications Ltd, New York.

Fleishman, E. A. (1998). "Patterns of leadership behavior related to employee grievances and turnover: Some post hoc reflections," *Pers. Psychol.* 51(4), 825-834. DOI:10.1111/j.1744-6570.1998.tb00740.x

Fu, L., Ding, M., and Zhang, Q. (2022). "Flood risk assessment of urban cultural heritage based on PSR conceptual model with game theory and cloud model – A case study of Nanjing," *J. Cult. Herit.* 58, 1-11. DOI:10.1016/j.culher.2022.09.017

Fu, X. Y., Huang, Z. Y., Lv, Q. Z., and Wang, Y. H. (2024). "Sustainable design strategies of educational furniture based on LCA methodology," *Pack. Eng.* 45(20), 183-191. DOI:10.19554/j.cnki.1001-3563.2024.20.016

Gayer, T., and Rosen, H. (2014). *Public Finance, Global Edition*, McGraw Hill, New York.

Hsu, C., and Sandford, B. A. (2007). "The Delphi technique: Making sense of consensus," *Practical Assessment, Res. Eval.* 12(1), 10. DOI: 10.7275/pdz9-th90

Hu, J. X., and Zhu, Z. (2023). "Study on the application of perceptual imagery theory in the design of campus public furniture," *Furniture Interior Design* 30(03), 31-35. DOI: 10.16771/j.cn43-1247/ts.2023.03.007

Jiao, J., and Zhang, Y. (2005). "Product portfolio planning with customer-engineering interaction," *IIE Trans.* 37, 801-814. DOI:10.1080/07408170590917011

Jin, Y. Z., and Xu, S. H. (2025). "Design of forest fire-fighting equipment based on UEM -AHP-FAST," *Mach. Design* 42(02),179-185. DOI:10.13841/j.cnki.jxsj.2025.02.030

Jin, Y. H., and Shen, D. S. (2024). "Method and model: research on classroom teaching e mpowered by learning space under the background of double reduction," *e-Educatio n Research* 45(01), 114-121. DOI:10.13811/j.cnki.eer.2024.01.015

Jing, Y. H., Yu, C. Q., Wang, P. J., and Shen, S. S. (2025). "The transformation of active learning space in the United States: Characteristics, morphology and strategies," *E-educ. Res.* 46(03), 114-121. DOI: 10.13811/j.cnki.eer.2025.03.016

Kapuria, T. K., Rahman, M., and Doss, D. A. (2020). "Users' satisfaction attributes analysis toward betterment of classroom furniture design for Bangladeshi university students," *J. Inst. Eng. India Ser. C* 101, 175-184. DOI:10.1007/s40032-019-00541-x

Kariippanon, K. E., Cliff, D. P., Okely, A. D., and Parrish, A. M. (2020). "The 'why' and 'how' of flexible learning spaces: A complex adaptive systems analysis," *J. Educ. Change* 21, 569-593. DOI:10.1007/s10833-019-09364-0

Ke, Q., and Chen, S. Y. (2022). "Research on the type of intelligent teaching space and the furniture function configuration strategy," *Furniture Interior Design* 29(02), 11-15. DOI: 10.16771/j.cn43-1247/ts.2022.02.003

Kendall, M. G., and Smith, B. B. (1939). "The problem of m rankings," *Ann. Mathem. Stat.* 10, 275-287. DOI: 10.1214/aoms/1177732186

Li, J. B., Han, Y. Q., and Meng, W. (2009). "Evaluation model of stakeholder satisfaction degree and its empirical research: from perspective of corporate governance," *Tech nol. Econ.* 28(03), 108-112. DOI:10.3969/j.issn.1002-980X.2009.03.021

Li, X. Y., Chen, Y. S., and Xu, W. (2022). "Research on the current situation and development trend of school furniture products," *Forestry Mach. Woodworking Equip.* 50(07), 16-23. DOI: 10.13279/j.cnki.fmwe.2022.0113

Liang, S. L. (2024). *Research on the Innovative Design of Shared Office Furniture Based on User Experience*, Master's Thesis, Shandong University of the Arts, Shandong, China.

Mi, Y. Q., Liu, Y. X., Fan, Y. N., Yin, Y. L., Zhang, J. P., Yu, H. H., Wang, X., Li, A. J., Luo, S., and Li, W. (2019). "Analyzing the status of incentives on community nurses in Shandong province based on the important quadrant model," *Chin. Health Serv. Manage.* 36(05), 336-338+386

Miao, Y. F., Sun, M., and Xu, Y. J. (2024). "Design and evaluation of ward companion furniture in inpatient department based on FAST-GRA-AHP," *China Forest Products Industry* 61(07), 40-47. DOI: 10.19531/j.issn1001-5299.202407008

Min, W. J., Chen, J. M., and Zhang, Z. Y. (2000). "Study on the evaluation index system and methods for information systems," *Journal of the China Railway Society* 22(5), 37-41. DOI: 10.3321/j.issn:1001-8360.2000.05.009

Morris, J. E., Imms, W., and Dehring, A. (2023). "The relationship among classroom furn iture, student engagement and teacher pedagogy," in: *Teachers as Researchers in In novative Learning Environment*, J. E. Morris, and W. Imms, W. (eds), Springer, Sin gapore. DOI:10.1007/978-981-99-7367-5_9

Nyimbili, P. H., and Erden, T. (2020). "A hybrid approach integrating entropy-AHP and GIS for suitability assessment of urban emergency facilities," *ISPRS Int. J. Geo-Inform.* 9(7), 419. DOI:10.3390/ijgi9070419

Oliver, R. L. (1997). *Satisfaction: A Behavioral Perspective on the Consumer*, The McGraw-Hill Companies, New York.

Petrov, A. I. (2022). "Entropy method of road safety management: Case study of the Russian federation," *Entropy*. 24, 177. DOI: 10.3390/e24020177

Saaty, T. L. (1980). *The Analytic Hierarchy Process*, McGraw-Hill, New York.

Saaty, T. L. (2008). "Decision making with the analytic hierarchy process," *Int. J. Serv. Sci.* 1, 83-98. DOI:10.1504/IJSSCI.2008.017590

Samuelson, P. A. (1954). "The pure theory of public expenditure," *Rev. Econ. Stat.* 36, 387-389. DOI:10.2307/1925895

Shang, K., Chen, Z., Chang, N., and Peng, X. (2021). "Evaluation of chair furniture comfort design based on entropy weight-VIKOR method," *Packaging Eng.* 42(14), 206-211. DOI:10.19554/j.cnki.1001-3563.2021.14.025

Shi, X. Y., Wu, X., Peng, M. Y., Zhang, Z. N., and Wang, Z. H. (2023). "Study on the construction of comprehensive evaluation index system of integrated health management and service ability of the close-knit medical consortium," *Chin. J. Health Policy* 16(11), 53-59. DOI: 10.3969/j.issn.1674-2982.2023.11.008

Smith, T. J. (2007). "The ergonomics of learning: Educational design and learning performance," *Ergonomics* 50, 1530-546. DOI:10.1080/00140130701587608

Su, X. Y. (2020). *Research on the Design of Primary and Secondary Schools to Educational Reform*, Master's Thesis, South China University Of Technology, Guangzhou, China. DOI: 10.27151/d.cnki.ghnlu.2020.000274

Takona, J. P. (2024). "Research design: Qualitative, quantitative, and mixed methods approaches / sixth edition," *Qual. Quant.* 58, 1011-1013. DOI:10.1007/s11135-023-01798-2

Tang, M., Li, R., Dai, X., Yu, X., Cheng, X., and Yang, S. (2024). "New electric power system stability evaluation based on game theory combination weighting and improved cloud model," *Sustainability* 16(14), article 6189. DOI: 10.3390/su16146189

The National Technical Committee for Standardization of Educational Equipment. (2014). "Functional size and technical requirements of school desks and chairs: GB/T 3976-2014," China Standards Press, Beijing, China.

Wang, C. Y., Ji, K. W., Zeng, Q., and Xia, Y. H. (2025). "Analysis of China's digital carb on footprint offset mechanism and strategy based on the three-party evolutionary ga me," *Resource Develop. Market*. https://link.cnki.net/urlid/51.1448.n.20250212.102 4.002.

Wang, J. S., Guo, Y. H., and Zhang, Y. B. (2022). "Comprehensive benefit evaluation of urban village reconstruction projects based on game theory with case studies in Gua ngzhou," *J. Civil Eng. Manag.* 39(06), 18-26. DOI: 10.13579/j.cnki.2095-0985.202 2.20211144

Wang, Y. J. (2005). *Evaluation of the Urban Village Reconstruction in Hangzhou City Based on the Hierarchical Analysis Method*, Master's Thesis, Zhejiang University, Hangzhou, China.

Wang, Q., and Chen, Y. S. (2024). "Actively study the evaluation of classroom furniture design," *Furniture* 45(06), 52-56+14. DOI: 10.16610/j.cnki.jiaju.2024.06.011

Wang, T. (2015). "Study of quarter map model on the income gap among industries," *Stat. Res.* 32(02), 31-36. DOI: 10.19343/j.cnki.11-1302/c.2015.02.005

Wang, Y. L., and Mao, M. Z. (2025). "Research on the quality improvement of the space under the overpass based on PSPL," *Anhui Arch.* 32(02), 13-16. DOI: 10.16330/j.cn ki.1007-7359.2025.2.04

Wang, Y., Zhang, C. M., and Wang, Z. H. (2013). "Study of the construction plan bid assessment method of the coal mine project based on entropy-weight method," *Appl. Mech. Mater.* 275, 274-2751. DOI:10.4028/www.scientific.net/amm.275-277.2748

Wood, J., Sarkani, S., Mazzuchi, T., and Eveleigh, T. (2012). "A framework for capturin g the hidden stakeholder system," *Syst. Eng.* 16(3), 251-266. DOI:10.1002/sys.21224

Wu, Z. Z., Zhao, J. X., and Sun, P. J. (2023). "Research on innovative design of office furniture based on Kano/AHP/QFD," *China Forest Products Industry* 60(11), 52-57. DOI:10.19531/j.issn1001-5299.202311008.

Xiao, D. B., Xie, W., Li, H. T., and Xiao, J. (2024). "Research on sustainable design of office furniture based on SET and AHP," *Furniture Interior Design* 31(10), 65-70. DOI: 10.16771/j.cn43-1247/ts.2024.10.011

Xie, W. T., and Xu, C. (2024). "Design of intelligent kitchen appliances for the elderly based on KJ-AHP-VIKOR integration method," *Packaging Eng.* 45(22), 411-419. DOI:10.19554/j.cnki.1001-3563.2024.22.040

Yao, X., Yang, H. G., Chen, B. Q., and Cao, Y. (2024). "Research on environmental risk assessment of river-type water sources based on game theory combination weighting method and cloud model," *Acta Sci. Circum.* 45(2), 177-189. DOI: 10.13671/j.hjkx xb.2024.0376

Zhang, X. Y., Kong, R., Li, X., and Tong, Z. P. (2024). "Research on weighting grade evaluation of hard roof stope based on game combination weighting-cloud model," *Mining Safety Environ. Protect.* 51(02), 98-105+110. DOI: 10.19835/j.issn.1008-4495.20230307

Zhang, S. T., Wang, F., Wang, S. J., Liu S. F., and Wang, H. Q. (2022).“Cultural and creative design of Gansu silk road bronzes based on combination weighting method of game theory," *Packaging Engineering* 43(08), 55-65. DOI: 10.19554/j.cnki.1001-3563.2022.08.008

Zhou, A. M., Ma, J., Zhang, S. T., and Wang, X. H. (2023). "Esthetic evaluation model of product form based on combination weighting method of game theory," *Pack. Eng.* 44(02), 34-40. DOI:10.19554/j.cnki.1001-3563.2023.02.004

Zhou, Y. D., and Chen, C. (2023). "Design of educational furniture service system for 'future learning center' based on KANO model," *Packaging Engineering* 44(18), 418-425. DOI: 10.19554/j.cnki.1001-3563.2023.18.050

Article submitted: November 23, 2024; Peer review completed: January 25, 2025; Revised version received: February 16, 2026; Accepted: March 21, 2025; Published: April 9, 2025.
DOI: 10.15376/biores.20.2.3971-3995