A Data-Driven Multi-Criteria Evaluation Framework for the Design Optimization of Children's Furniture

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To enhance the scientific rigor and user alignment of children's furniture design, this study proposes a data-driven multi-criteria evaluation framework for design optimization. Focusing on wooden seating products for children, online product reviews were collected and preprocessed using Python and the Jieba word segmentation tool to extract authentic user needs. An evaluation index system was established by filtering indicators through expert focus group discussions and the coefficient of variation method. During the weighting phase, subjective weights were derived using an improved Analytic Hierarchy Process (AHP), while objective weights were calculated *via* the CRITIC method. A game-theoretic approach was employed to integrate both into a composite weight vector. Finally, the TOPSIS–RSR model was applied to rank and classify the performance levels of four wooden children's seating designs. Based on the results, specific design guidance strategies were proposed. The proposed framework effectively captures user requirements, balances subjective and objective information, and provides a clear decision-making pathway for selecting optimal design solutions. The study not only advances theoretical research but also offers practical guidance for design, with strong potential for extension to other furniture categories and resource-driven product design domains.

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INTRODUCTION

As China undergoes a demographic transition marked by population aging and declining birth rates, the children's goods market is encountering both new challenges and emerging opportunities. As an integral part of the child's developmental environment, children's furniture not only fulfills everyday functional needs but also exerts a profound influence on children's physical and mental well-being, behavioral development, and family interactions (Wen and Pashkevych 2023). In China, fertility-policy reforms and shifting consumption patterns have raised expectations for children's furniture, especially for safety, multifunctionality, and emotional value (Zhu *et al.* 2024). Here, fertility-policy refers to China's recent optimization of fertility policy, in particular the 2021 three-child policy and its supporting measures that aim to reduce costs associated with child-rearing and education (State Council of the People's Republic of China 2021). Moreover, the unique characteristics of different child development stages have introduced higher design demands for such products (Yu *et al*. 2024). Despite these trends, current children's furniture design faces several limitations, including a narrow functional scope, insufficient user needs analysis, and a strong reliance on subjective design perspectives, which together hinder the ability of products to fully address the diverse needs of both children and their caregivers (Yang and Zhao 2024).

Child psychologist Jean Piaget emphasized that children acquire knowledge through interaction with their surrounding environment, gradually developing social cognition and self-identity (Piaget and Cook 1952; Luo *et al.* 2025). As a central medium through which children engage with the home environment, the design quality of children's furniture directly affects parent–child relationships and the overall developmental experience of children (Ginsburg 2007; Miao *et al*. 2024). Well-designed furniture not only improves comfort and safety in use but can also support behavioral guidance and emotional bonding through playful and emotionally resonant design features. Children's furniture design is inherently a complex and systematic process that must comprehensively address user needs while establishing a scientific framework to guide the development of children's furniture, ensuring both scientific rigor and efficiency in product development. However, current research in this field predominantly focuses on safety performance or aesthetic optimization, with relatively limited attention to children's authentic needs and the broader expectations of family users (Luo *et al*. 2025). Moreover, traditional design and evaluation methods often rely heavily on designers' subjective judgment, lacking systematic data support. This compromises both the scientific basis and market alignment of resulting design decisions (Liu 2025). Therefore, integrating user-need mining, expert judgment, and objective data into the design-decision process can overcome the limitations of single-method approaches. Such integration enhances the rationality of design indicators and enables more accurate characterization of product features, thereby offering objective data-driven support and decision-making references for design optimization and solution selection (Liu 2025).

To address the aforementioned challenges, this study takes wooden children's seating as a case example and proposes a data-driven multi-criteria evaluation framework aimed at optimizing the scientific rigor of the design and assessment process for children's furniture. By integrating online review mining, expert judgment, and multi-criteria decision-making methods (improved AHP, CRITIC, and TOPSIS–RSR), the goal was to construct a comprehensive evaluation index system to quantify user needs and support the selection of optimal design solutions. The study not only provided both theoretical grounding and practical guidance for the design of wooden children's seating but also aimed to reduce the influence of subjective bias in the design process, enable more rational decision-making, and enhance user satisfaction. Moreover, the proposed approach contributes to aligning furniture design more precisely with market expectations and user demands. It also offered a replicable and adaptable reference framework for the development of similar children's furniture, thereby further promoting a transition from experience-based design toward a more scientific and systematic design paradigm.

Literature Review

The design of children's furniture has attracted considerable global scholarly attention, with many researchers exploring optimization strategies from multiple perspectives and achieving meaningful progress. A comprehensive review of existing literature reveals that current research primarily has focused on two key areas: functional enhancement and the psychological needs of children. However, notable limitations persist, providing both a theoretical foundation and opportunities for improvement in this study. First, several studies have concentrated on the functional performance, safety, and sustainability of children's furniture. For instance, Struzikiewicz *et al*. (2024) employed the APEKS decision model to optimize the functionality and manufacturing efficiency of therapeutic furniture for children, proposing a design method that balances practicality with production feasibility. Phuah *et al*. (2025) developed multifunctional and reusable children's furniture through stress analysis and material optimization, thereby extending product lifespan. Mou *et al*. (2024) combined Case-Based Reasoning (CBR) and the Theory of Inventive Problem Solving (TRIZ) to design furniture adaptable to various stages of child development, emphasizing sustainability and functional scalability. While these studies provide valuable insights into functional improvements, they primarily have focused on isolated features or material enhancements, often overlooking emotional needs and the broader context of family usage scenarios (Luo *et al*. 2025). Second, some researchers have approached the issue from the perspective of child cognitive psychology, translating children's needs into quantifiable data to inform furniture design. For example, Zhu *et al*, (2024) conducted a literature review and identified twelve psychological need variables critical to children's furniture design, underscoring their impact on user satisfaction and market competitiveness. Hao and Guan (2025) developed an innovative evaluation model for pediatric clinic furniture by integrating Kansei Engineering and aesthetic assessment methods. Wang *et al*. (2024) emphasized the importance of accommodating children's functional preferences and emotional engagement to enhance the overall user experience. These efforts mark progress in the quantification of user needs. However, they are largely limited to static analysis and fail to fully account for the dynamic developmental stages of children and the long-term adaptability such changes demand from furniture design (Liu 2025). In addition, this study systematically reviewed literature related to evaluation and decision-making in children's furniture design. Some works have attempted to incorporate structured tools to improve the scientific rigor of design decisions. For example, Yu *et al*. (2024) and Yu *et al*. (2023) adopted the AHP to construct evaluation models for children's furniture design, using weighted scoring to inform practice. However, traditional AHP methods rely heavily on subjective judgment, and the absence of robust quantitative standards undermines the objectivity of the evaluations. Furthermore, current studies rarely integrate multiple data sources, including user reviews, expert opinions, and market feedback, resulting in decision processes that are not comprehensively supported by data (Yang and Zhao 2024). In contrast, research integrating hybrid subjective–objective weighting and multi-criteria decision-making methods remains insufficient. This gap is especially evident in the field of children's furniture design, where the development of systematic evaluation models still requires further exploration.

In summary, existing studies have proposed solutions for children's furniture design from various perspectives. To some extent they have contributed to enhancing product value through design-centered approaches. However, several notable limitations remain. First, most research focuses on functionality or aesthetics while neglecting the dynamic nature of children's developmental needs and the emotional expectations of the family unit. Second, traditional design methodologies are largely reliant on subjective experience and lack a data-driven, systematic evaluation framework. Third, current evaluation models, such as AHP, exhibit limitations in weight assignment and multi-indicator synthesis. These limitations hinder a comprehensive representation of user needs and reduce the objectivity and scientific basis of design solutions. To address these challenges, this study takes wooden children's seating as the research focus and proposes a data-driven multi-criteria evaluation framework that integrates online review mining, an improved AHP, the CRITIC method, and the TOPSIS–RSR model. Specifically, the contributions of the present study are fourfold: (i) an improved AHP that triangulates arithmetic-mean, geometric-mean, and eigenvector estimators under explicit CI/CR consistency control to improve the robustness of subjective weights; (ii) a game-theoretic fusion of AHP (subjective) and CRITIC (objective) weights that balances expert judgment with data-driven information and preserves inter-indicator correlations; (iii) an enhanced TOPSIS–RSR pipeline in which a relative-distance index replaces the conventional closeness coefficient (avoiding the "0.5 defect"), and RSR with Probit mapping converts continuous scores into statistically interpretable performance tiers, yielding actionable guidance beyond ranking; and (iv) a data-to-design evidence chain tailored to wooden children's seating, comprising e-commerce review mining, KJ consolidation, and coefficient-of-variation filtering, which results in a 4-criterion/21-sub-criterion evaluation system operationalizing safety, interaction, visual, and emotional needs for downstream optimization. Compared with prior AHP/TOPSIS-style studies on children's furniture, our framework uniquely balances subjective and objective information, provides graded recommendations rather than only rankings, and strengthens weight robustness via estimator triangulation, while implementing an end-to-end design-oriented pipeline for wooden seating. While CRITIC and TOPSIS–RSR have proven effective in other domains, their combined use within children's furniture design remains underexplored, which constitutes the methodological novelty here. The goal was to construct a scientifically sound evaluation system and support the optimization of design decision-making. Unlike traditional approaches based on designers' subjective judgments, the proposed model aimed to objectively determine indicator weights during the user needs acquisition phase, thereby enhancing the scientific validity and rationality of design alternatives. This helps design practitioners implement more precise and evidence-based strategies that promote healthy development in children. Moreover, the findings are expected to offer children's furniture manufacturers a scientific and efficient process framework along with theoretical support, thereby contributing to the advancement of the children's furniture market.

EXPERIMENTAL

Collection of Online Review Text Based on Python

With the rapid development of the e-commerce industry, a vast volume of product review data has been generated across various online shopping platforms in China. These user-generated reviews carry significant value for research in furniture design (Yang 2024). In parallel, many scholars have utilized online review data to conduct in-depth analyses of user needs, thereby proposing innovative design methodologies grounded in user feedback (Yang and Zhao 2024). Leveraging online reviews enables the extraction of dynamic user requirements from e-commerce platforms, offering more accurate and real-time feedback for design innovation in children's furniture. This approach also provides a robust scientific basis for product iteration and enhancement. To gain a better understanding of user needs, this study employed Python in combination with the Jieba word segmentation tool to process the collected data. The procedure involved several stages: review collection, data preprocessing, text analysis, data mining, and visual presentation. The detailed process is illustrated in Fig. 1.

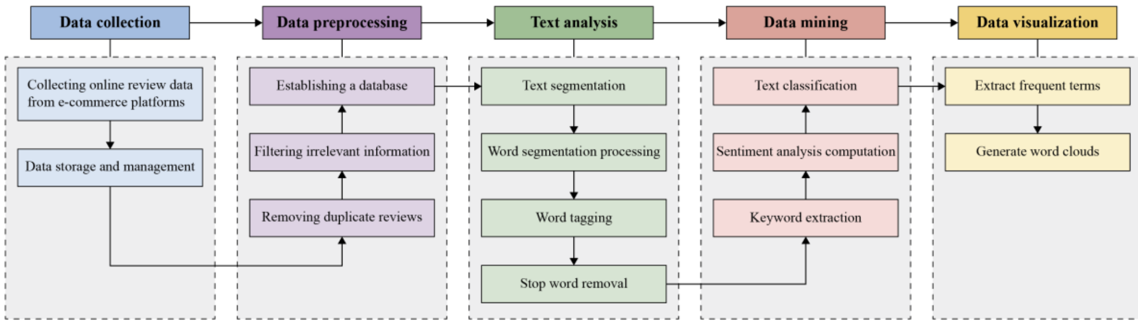

Fig. 1. Online review data processing

Relevant review data for the target children's furniture products were collected from representative e-commerce platforms using Python, with a primary focus on ensuring data quality and accuracy at this stage. Second, data preprocessing was used to remove duplicate entries, irrelevant content, and erroneous information, thereby establishing a structured review database. Next, the Jieba word segmentation tool was applied to segment the text, eliminate stop words, extract keywords, and calculate sentiment tendencies to enhance the relevance and specificity of the data. Following this, sentiment analysis was performed to obtain a comprehensive understanding of users' overall evaluations and feedback on the target products. Word cloud visualizations were used to display high-frequency terms, providing intuitive insights into user needs.

Improved AHP-CRITIC Combined Weighting Method

The core of the combined weighting method lies in determining the relative importance of each evaluation criterion, as the assigned weights reflect the contribution of each indicator to the overall assessment. Achieving a scientific and objective allocation of weights is a critical component of the evaluation process. This study introduces an innovative approach by integrating an improved AHP with the CRITIC method, complemented by game theory principles. This hybrid approach enables the coordinated processing of both subjective and objective information, enhancing the rationality of weight determination and improving the efficiency of leveraging inter-criteria correlations.

The Analytic Hierarchy Process (AHP), proposed by Saaty in the 1970s (Saaty 1980), integrates both qualitative analysis and quantitative reasoning, and is characterized by its hierarchical and systematic structure. In the context of children's furniture design, which involves complex and dynamic decision-making challenges, AHP facilitates the decomposition of intricate problems into a structured hierarchy, thereby simplifying the evaluation process. However, given that traditional AHP methods are often criticized for their strong subjectivity in weight calculation, the prsesent study adopted an improved approach inspired by recent research. Three computational techniques were integrated to analyze the judgment matrix: the arithmetic-mean (AM), geometric-mean (GM), and eigenvalue methods. This integration enhances both the objectivity and the robustness of the weight evaluation process (Yuan *et al*. 2024). Specifically, conventional AHP typically derives a single set of weights from the group judgment matrix after the consistency check, most often using the principal eigenvector method. In the present approach, the choice of weighting estimator is treated as a source of model uncertainty. Therefore, three classical estimators were run in parallel on the aggregated group matrix. Then the final subjective weights were run through equal weight consensus. Prior studies indicate that these estimators differ in sensitivity and stability, and that the geometric mean solution is widely used in group AHP settings (Yuan *et al*. 2024; Vinogradova-Zinkevič 2023). Aggregation across methods helps reduce the bias of any single method and improves robustness. In this application, because the study involves multiple experts and early stage design indicators, judgments often display mild inconsistency and estimator sensitivity. Using multiple weighting computations mitigates data volatility while preserving the interpretability of AHP (Mazurek *et al*. 2021).

The first step involves constructing a comprehensive judgment matrix for the design evaluation criteria. In this process, pairwise comparisons are conducted among the indicators using the 1-to-9 scale method, resulting in a comparison matrix, as shown in Eq. 1. Moreover, the judgment matrix must satisfy the condition of positive reciprocal consistency to ensure the logical coherence of the subsequent weight calculations,

$$\boldsymbol{A} = (a_{ij})_{n\times n} \tag{1}$$

where $a_{ij}=1/a_{ji}$, $a_{ii}=1$.

The arithmetic mean method involves normalizing the pairwise comparison matrix $\boldsymbol{A}$ column by column to obtain a standardized judgment matrix. Subsequently, the arithmetic mean of each row in the normalized matrix is calculated to derive the weight vector, as shown in Eq. 2,

$$a_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n}a_{ki}} \quad (i = 1,2,\cdots,n) \tag{2}$$

where a_{ij} denotes the element located in the i-th row and j-th column of the judgment matrix; n represents the total number of evaluation criteria; $\sum_{k=1}^{n}a_{ki}$ is the sum of the elements in the j-th column of the matrix (used for normalization); and a_i refers to the weight of the i-th criterion calculated using the arithmetic mean method.

The geometric mean method entails normalizing the pairwise comparison matrix A column by column to obtain a standardized judgment matrix, followed by calculating the geometric mean of each row in the normalized matrix. This yields the corresponding weight vector, as shown in Eq. 3,

$$\beta_i = \frac{\prod_{j=1}^{n}a_{ij}^{1/n}}{\sum_{n}^{k=1}\left(\prod_{j=1}^{n}a_{kj}\right)^{1/n}} \quad (i = 1,2,\cdots n) \tag{3}$$

where the definition of a_{ij} is the same as previously described; $\prod_{j=1}^{n}a_{ij}$ represents the product of all elements in the i-th row; and β_i denotes the normalized weight of the i-th criterion calculated using the geometric mean method.

The eigenvalue method involves standardizing the pairwise comparison matrix A, then computing its principal eigenvalue and the corresponding eigenvector. This eigenvector is subsequently normalized to obtain the final weight vector for all evaluation criteria, as shown in Eq. 4,

$$\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(\boldsymbol{A}\omega)_i}{\omega_i} \tag{4}$$

where ω_i represents the normalized weight of the i-th criterion calculated using the eigenvalue method; $\boldsymbol{A}\omega$ denotes the product of the judgment matrix A and the weight vector ω; and $\lambda_{\max}$ is the maximum eigenvalue of the judgment matrix.

The indicator weights are then computed using equal weight consensus, which represents a substantive improvement over conventional AHP. To ensure the rationality of the judgment results, the eigenvalue method requires a consistency check of the computed judgment matrix to eliminate contradictions caused by subjective bias. This verification is carried out using Eq. 5 and Eq. 6. If the consistency ratio (CR) is less than 0.1, the matrix is considered to have passed the consistency test,

$$I_{\mathrm{C}} = \frac{\lambda_{\max} - n}{n-1} \tag{5}$$

where I_C denotes the consistency index, and $\lambda_{\max}$ has the same meaning as previously defined.

$$R_C = \frac{I_C}{I_R} \tag{6}$$

In Eq. 6, I_C is as previously defined; R_C represents the consistency ratio; and I_R refers to the random consistency index, which can be obtained from a standard reference table.

The improved AHP method treats the research object as a system and adopts a more integrated approach to decision-making, thereby reducing subjective bias and enhancing both the robustness of the calculations and the rationality of the derived weights. This makes it particularly suitable for addressing multi-criteria decision problems in the context of children's furniture design. The improved AHP effectively models diverse design indicators and unstructured problems, offering solid theoretical support for decision analysis in complex design scenarios. However, AHP still exhibits limitations in terms of evaluation comprehensiveness. Therefore, it is necessary to further incorporate the Criteria Importance Through Intercriteria Correlation (CRITIC) method to achieve a balanced weighting of evaluation criteria (Wei *et al*. 2021).

The CRITIC method, proposed by Diakoulaki, is an objective weighting approach that determines indicator weights based on the variability and conflict intensity among evaluation criteria (Diakoulaki and Mavrotas 1995). When applied in this study, the CRITIC method enables a balance between subjective and objective factors, resulting in more rational weight assignments for the design indicators of children's furniture.

The CRITIC method does not rely on expert judgment; instead, it assigns weights based on the intrinsic statistical characteristics of the indicators themselves. The calculation of objective weights is primarily based on two indices: variability (contrast intensity) and conflict (degree of correlation). The specific computation of variability is shown in Eq. 7,

$$S_j = \sqrt{\frac{\sum_{i=1}^{m} \left(x_{ij} - \bar{x}_j\right)^2}{n-1}} \tag{7}$$

where S_j represents the standard deviation of the j-th indicator; x_{ij} is the original value of the i-th evaluation object on the j-th indicator; $\bar{x}_j$ denotes the mean value of the j-th indicator; and m is the total number of samples.

The calculation of conflict requires the use of the correlation matrix of the indicators, as shown in Eq. 8,

$$r_{ij} = \frac{\sum_{j,k=1}^{n} (x_{ij} - \bar{x}_j)(x_{ik} - \bar{x}_k)}{\sqrt{\sum_{j=1}^{n} \left(x_{ij} - \bar{x}_j\right)^2 \sum_{k=1}^{n} (x_{ik} - \bar{x}_k)^2}} \tag{8}$$

where r_{ij} denotes the correlation coefficient between indicator j and indicator k; all other symbols are as previously defined.

The calculation of conflict is given in Eq. 9,

$$A_j = \sum_{i=1}^{n}(1 - r_{ij}) \tag{9}$$

where A_j represents the conflict degree of indicator j (a higher value indicates greater independence); n is the total number of indicators; and the closer $1 - r_{ij}$ is to 1, the less correlated the indicators are.

Accordingly, the final weight calculation is defined in Eq. 10,

$$n_j = \frac{S_j A_j}{\sum_{j=1}^{n} S_j A_j} \tag{10}$$

where n_j denotes the CRITIC weight of the j-th indicator; S_jA_j represents the amount of information carried by the indicator (the larger the value, the greater the importance); and $\sum_{j=1}^{n} S_j A_j$ is the total amount of information across all indicators, used for normalization.

The aforementioned objective weighting method enables a comprehensive evaluation of both the differences and interrelationships among the indicators of children's furniture. It effectively uncovers latent correlations within the sample data, thereby enhancing the objectivity and precision of the overall evaluation framework.

The use of a single weighting method often introduces subjective bias and partiality, necessitating the construction of a comprehensive influence model to mitigate such drawbacks. To address conflicts such as incompatibility between traditional single-theory models, this study adopts a game-theoretic approach to integrate the two sets of weights. The method allows for conflict adjustment and fusion based on the combined weights (Liu *et al*. 2024). The game-theory-based combined weighting method accounts for the divergence among the weights of children's furniture design indicators while preserving as much original information as possible, thereby improving the overall accuracy of the weighting process.

First, the construction of the combined weight vector is defined in Eq. 11,

$$w_3^T = a_1 w_1^T + a_2 w_2^T \tag{11}$$

where w_1^T represents the initial subjective weight vector, w_2^T denotes the objective weight vector, and w_3^T refers to the final combined weight vector.

To optimize the two linear combination coefficients, the objective function was established as shown in Eq. 12.

$$min\|\sum_{v=1}^{2} a_v w_v^T - w_z^T\|_2 (z = 1, 2) \tag{12}$$

By taking the derivative of Eq. 12 and applying the properties of matrix differentiation, the optimization problem is transformed into a condition based on the first-order derivative, leading to Eq. 13.

$$\begin{bmatrix} \mathrm{w}_1 \cdot \mathrm{w}_1^{\mathrm{T}} & \mathrm{w}_1 \cdot \mathrm{w}_2^{\mathrm{T}} \\ \mathrm{w}_2 \cdot \mathrm{w}_1^{\mathrm{T}} & \mathrm{w}_2 \cdot \mathrm{w}_2^{\mathrm{T}} \end{bmatrix} \times \begin{bmatrix} \alpha 1 \\ \alpha 2 \end{bmatrix} = \begin{bmatrix} \mathrm{w}_1 \cdot \mathrm{w}_1^{\mathrm{T}} \\ \mathrm{w}_2 \cdot \mathrm{w}_2^{\mathrm{T}} \end{bmatrix} \tag{13}$$

By solving Eq. 13, the final combination coefficients $a_h (h = 1, 2)$ are obtained, followed by normalization of these coefficients, as shown in Eq. 14.

$$a_h^* = \frac{|a_h|}{\sum_{h=1}^{2}|a_h|} \tag{14}$$

Finally, the normalized coefficients are applied to compute the weighted combination, resulting in the final combined weights, as presented in Eq. 15.

$$w_3^T = a_1^* w_1^T + a_2^* w_2^T \tag{15}$$

The improved AHP is based on the magnitude of data values, while the CRITIC method relies on data variability and conflict. Building on these foundations, the introduction of game theory enables the derivation of a more credible and reliable integrated weighting result.

TOPSIS-RSR Decision Evaluation Model

The technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method is a multi-objective decision-making approach commonly applied in engineering and design evaluation. TOPSIS ranks multiple design alternatives based on their distances to the positive and negative ideal solutions, thereby identifying the optimal solution (Luo and Fang 2024). However, when the distances to the ideal and anti-ideal solutions are equal, the relative closeness coefficient becomes 0.5 for all alternatives, and the method fails to differentiate among them. This issue is referred to as the "relative closeness defect" (Yuan *et al*. 2024). To address this limitation, the relative distance index L_i is introduced to replace the traditional closeness coefficient C_i, forming an improved version of the TOPSIS method, as shown in Eq. 16.

$$L_i = \sqrt{[D_i^+ - \min(D_i^+)]^2 + [D_i^- - \max(D_i^-)]^2} \tag{16}$$

The fundamental concept of the improved TOPSIS method is illustrated in Fig. 2. In the figure, the horizontal axis represents the Euclidean distance between an evaluation object and the positive ideal solution, while the vertical axis represents the Euclidean distance to the negative ideal solution. Points A_1 and A_4 serve as reference points for the positive ideal solution, whereas points A_2 and A_3 illustrate the specific distance ranges between the evaluation objects and both the positive and negative ideal solutions. It can also be observed that for points B_1 and B_2, the distances to both the positive and negative ideal solutions are equal. As a result, the traditional TOPSIS method cannot effectively or distinctly differentiate between these two evaluation objects. To address this issue, the improved TOPSIS method replaces the traditional closeness coefficient with a relative distance measure, thereby overcoming this limitation and enhancing the applicability of the comprehensive evaluation algorithm.

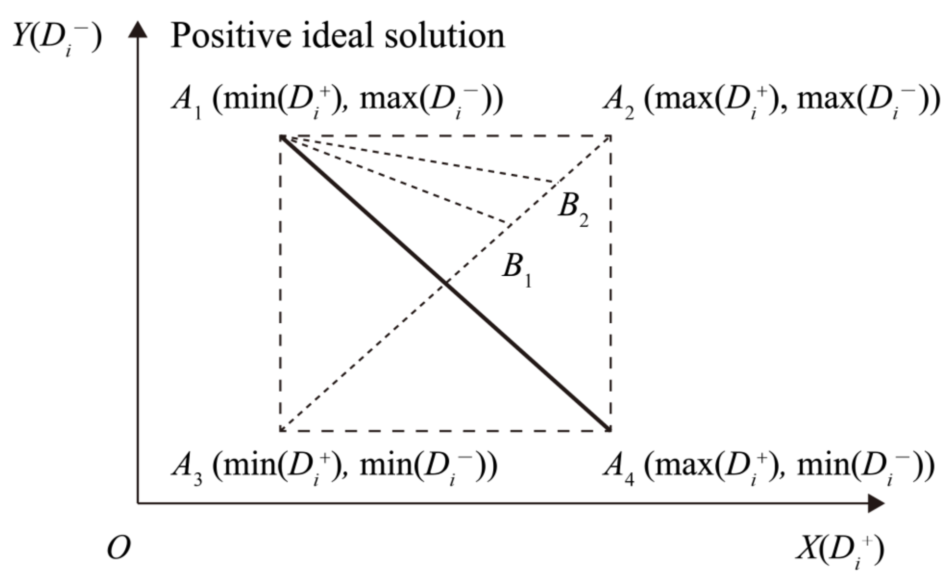

Fig. 2. Basic concept of improved TOPSIS method

By integrating the distance values and the relative distance index, the comprehensive score L_i is calculated by Eq. 16. The alternatives are then ranked according to their L_i values, yielding the final ranking results of the improved TOPSIS method.

The Rank Sum Ratio (RSR) method, developed by Chinese statistician Professor Tian Fengdiao, is a widely applied statistical analysis technique for multi-criteria evaluation of alternatives (Yin *et al*. 2025). The core concept involves transforming the ranks within an n-row by m-column matrix to generate a dimensionless statistic W. Based on this, parametric statistical analysis is applied to examine the distribution of W, which in turn enables the ranking or classification of evaluation objects according to their relative performance.

The improved TOPSIS method yields continuous scoring results, which can be difficult to interpret directly for practical decision-making due to the lack of clear grade classifications. At the same time, the traditional RSR method faces limitations in multi-criteria evaluations, such as insufficient discriminative power and the potential loss of original data information during the ranking process, making it challenging to accurately reflect differences in indicator importance.

This study incorporated the RSR method to normalize the rank order of the comprehensive scores obtained from the improved TOPSIS approach. By combining this with a scoring distribution-based classification scheme, more rational performance levels can be established. This integration offers a more scientific basis for selecting the optimal children's furniture design solution. Specifically, the L_i values obtained from the improved TOPSIS method are ranked and assigned as rank values R_i, as shown in Eq. 17,

$$R_i = \mathrm{rank}(L_i) \tag{17}$$

where R_i represents the rank of the i-th object among all evaluation scores.

After determining the ranks and corresponding R_i values, the cumulative downward frequency F_i (*i.e.*, relative rank) is calculated, as shown in Eq. 18,

$$F_i = \frac{R_i}{n} \tag{18}$$

where F_i denotes the cumulative downward frequency of the i-th object, and n represents the total number of evaluation objects.

The F_i values are converted into probability unit values (Probit), which are then used as the independent variable, while the L_i values serve as the dependent variable in a univariate linear regression analysis, resulting in the regression equation shown in Eq. 19. Finally, the fitted W values obtained from the regression equation are used to classify the evaluation objects into performance levels.

$$L_i = a + b \times Probit_i + \varepsilon_i \tag{19}$$

where a is the regression intercept, b is the regression slope, and ε_i is the residual error.

The TOPSIS–RSR decision evaluation model not only retains the mathematical strengths of TOPSIS in multi-criteria weighted assessment, but it also enhances the interpretability and classification capability of the evaluation results through the integration of RSR. Moreover, the model minimizes the loss of original data and improves the intuitiveness and credibility of the evaluation outcomes for children's furniture design, thereby achieving a complementary synergy between the two methods.

Design Research Process

Following the detailed discussion of the theoretical foundation and evaluation framework construction, it is essential to further clarify the technical roadmap and implementation process to ensure the practical effectiveness and operability of the proposed framework. Building on three preparatory stages (user-semantic mining, indicator screening, and weight calculation), we establish a cohesive workflow that integrates data collection, indicator development, weight integration, and model-based evaluation.

Specifically, this study systematically constructed and validated an evaluation and optimization framework for children's furniture design through four sequential stages, as illustrated in Fig. 3. (1) Python tools were used to mine online consumer reviews of the target children's furniture products. These data were analyzed to uncover actual user needs, and the results were visualized using word cloud diagrams. (2) Indicator construction was employed *via* expert card sorting (KJ inspired, affinity style) and coefficient of variation screening. Building on a systematic review of relevant literature, a market investigation of existing products, and user interviews, the concrete design requirements were organized based on the production of concise "concept cards." Two domain experts in children's furniture and one methods researcher independently grouped the cards without preset categories and proposed short labels. Disagreements were resolved in a consensus meeting.

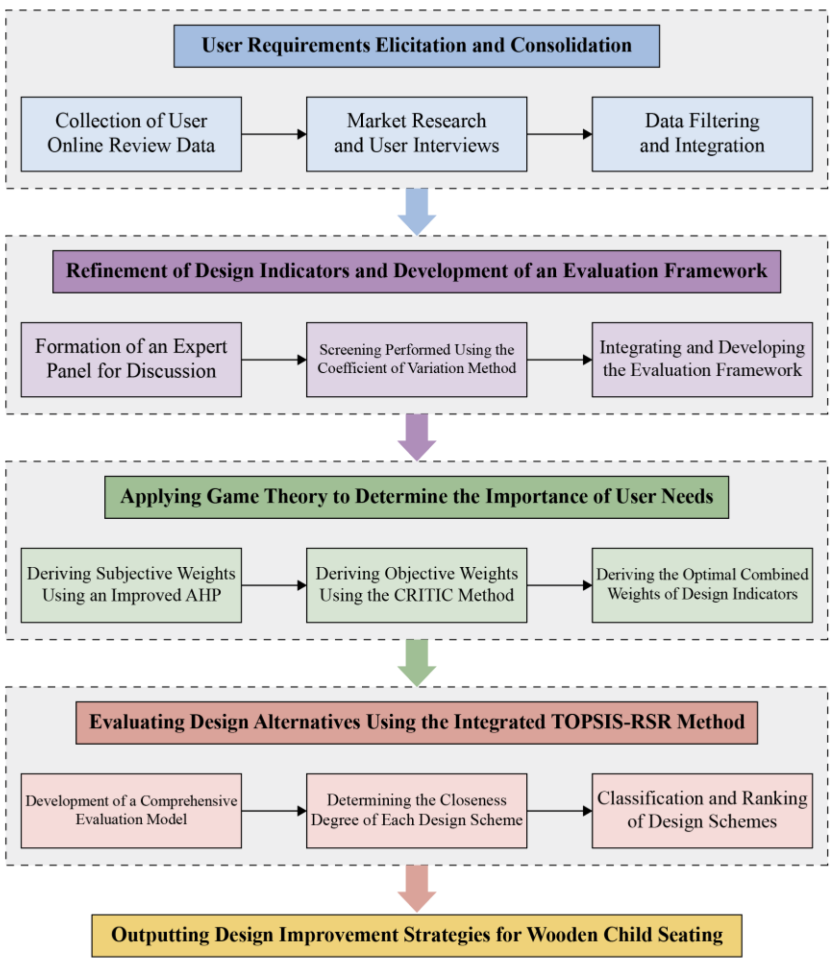

Fig. 3. Design research flow chart

Each cluster was then named and defined in a single sentence and hierarchically rolled up to form criterion level categories and their associated design indicators tailored to the target children's furniture. In addition, the coefficient of variation method was applied for a second round of consolidation to further streamline, refine, and summarize the indicators, thereby constructing the evaluation index system for the product category. (3) The improved AHP and the CRITIC method were applied to obtain the subjective and objective weights of the design indicators. Game theory was then introduced to derive the optimal combined weights, effectively addressing the subjectivity issues inherent in single-method approaches. Based on these weights, a TOPSIS–RSR decision evaluation model was established. This model was used to conduct a classification-based evaluation of four wooden children's furniture design schemes, from which the optimal design was selected, thereby demonstrating the validity of the proposed framework. (4) Finally, the proposed model is compared with traditional methods such as Fuzzy Comprehensive Evaluation (FCE), Grey Relational Analysis (GRA), and Entropy Weight Method (EWM) to validate its accuracy and effectiveness in design decision-making.

RESULTS AND DISCUSSION

Children's Furniture Design Evaluation Framework

Following the construction of the methodological framework, the next step was to verify its applicability and effectiveness through a systematic empirical process. Accordingly, this section focuses on implementing the previously established evaluation index system and framework to conduct detailed weight calculations and design scheme optimization. The aim was to assess the explanatory power and operational feasibility of the proposed framework in practical design decision-making, thereby providing solid empirical support for the scientific design of children's furniture.

Wood has become the primary material in children's furniture design due to its flexibility in design, expressive form, structural stability, safety, and environmentally sustainable characteristics (Zhang and Song 2024). Research indicates that, among furniture types, seating products most clearly reflect user attributes in both function and form because they are highly constrained by use. Therefore, selecting seating as the entry point for children's furniture design research offers strong representativeness (Han *et al*. 2025). Based on this rationale, the present study constructs a scientifically grounded evaluation index framework using wooden children's seating as the research subject.

User Demand Mining

First, Python scripts was implemented to collect online reviews from the e-commerce platform JD.com for multiple wood-based children's seating products over the past seven months (only publicly accessible pages were used; no login was required and no personally identifiable information was collected). JD.com was selected as the primary data source because its children's-furniture taxonomy is clear, the review volume is large, and the product and review fields are well structured, which facilitates reproducible, rule-based filtering. In addition, recent peer-reviewed studies have widely used JD.com review data for topic extraction, sentiment analysis, and review-based product evaluation, supporting the scholarly validity and acceptance of this source (Shan *et al.* 2024). For retrieval, the authors navigated to the relevant category paths and used keywords such as "children's chair," "children's seating," "study chair," "growable chair," and "high chair," while applying attribute filters for material and age suitability. To mitigate potential bias from platform ranking, data were collected under multiple sort views, including comprehensive, sales, and rating, and duplicate products were removed. For each review, the extracted items included the review date, any child age group mentioned in the text, the username, the rating level (positive, neutral, or negative), and the review content. In total, 7,691 records were obtained; after removing irrelevant or duplicate reviews, 6,802 valid entries remained for analysis (See Appendix for specific code). Next, the Jieba word segmentation tool was used to segment the text database. For example, the sentence "This children's chair has great stability, and the appearance is beautiful. I'm very satisfied." was segmented into keywords such as "stability", "appearance", and "aesthetic." Word annotation was performed, followed by removing removed stop words and filtering out meaningless terms. Subsequently, word frequency statistics and sentiment polarity calculations were conducted to analyze users' overall evaluations of the products. Finally, a word cloud was generated to highlight users' key concerns regarding wooden children's seating, as shown in Fig. 4.

Fig. 4. User needs word cloud

Demand Integration and Indicator Screening

The word cloud served as the initial representation of user needs for wooden children's seating. From January to April 2025, additional user requirements were collected through literature review, market investigation, and user interviews. In May 2025, a panel of experts was invited, comprising children's furniture designers and university faculty members, to review and refine the indicators. Through this process, four primary design dimensions were identified (visual needs, safety needs, interaction needs, and emotional needs), along with 32 secondary-level indicators. To enhance the sensitivity and discriminative power of the indicator system, the experts were asked to rate the importance of the 32 identified indicators using a 100-point scale. These scores were then analyzed using the coefficient of variation method to conduct a second round of indicator screening and finalize the evaluation criteria. During the construction of a multi-criteria evaluation system, if the variation of a given indicator across evaluation objects is minimal, its contribution and discriminative capacity become limited, potentially overshadowing more critical indicators. To improve both efficiency and clarity, this study applied the coefficient of variation method to filter the initially consolidated 32 design indicators. A greater coefficient of variation indicated higher information content of the indicator—ensuring it has a significant impact on the evaluation of wooden children's seating design.

To eliminate the influence of differing data dimensions on indicator selection, a dimensionless normalization process was applied, as shown in Eq. 20,

$$P_{jk} = \frac{V_{jk} - \min_{1 \ll k \ll m}(V_{jk})}{\max_{1 \ll k \ll m}(V_{jk}) - \min_{1 \ll k \ll m}(V_{jk})} \tag{20}$$

where P_{jk} denotes the normalized score given by the k-th expert for the j-th indicator, and V_{jk} represents the original score assigned by the same expert.

Next, let r_j represent the coefficient of variation for the j-th indicator. The formula for calculating the coefficient of variation is given in Eq. 21, and the formula for calculating the mean is provided in Eq. 22, as follows,

$$r_j = \frac{\sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(x_{jk} - \bar{x}_j\right)^2}}{\bar{x}_j} \tag{21}$$

$$\bar{x}_j = \frac{1}{n}\sum_{j=1}^{n} x_{jk} \tag{22}$$

where x_{jk} denotes the score given by the k-th expert for the j-th indicator; $\bar{x}_j$ represents the mean score of the j-th indicator; and n is the total number of experts.

A higher coefficient of variation indicates greater differentiation in the data for a given indicator, signifying a stronger influence on the overall evaluation outcome of wooden children's seating. By applying Eqs. 20 through 22 to the expert scoring data, only those indicators with a coefficient of variation exceeding the mean were retained, completing the second round of indicator refinement. The results are presented in Table 1. Based on the screening outcome, an evaluation system for wooden children's seating was constructed in Fig. 5, comprising four criteria-level indicators and twenty-one sub-criteria indicators. According to Donald Norman's three-level theory of emotional design, the four criteria-level indicators correspond to the visceral, behavioral, and reflective levels (Norman 2013). Similarly, Jordan (1998) defines user needs from the perspective of product characteristics as consisting of three layers: functionality, usability, and pleasure. These theories offer valuable frameworks for understanding user psychology and design requirements, thereby providing a solid theoretical foundation for the development of the evaluation system and the subsequent design of wooden children's seating.

Specifically, the visceral level focuses on users' immediate perceptions of the product, including visual elements such as form, color, and material. Accordingly, the first primary criterion at this level is C_1: Visual Needs. The behavioral level emphasizes the practicality and usability of furniture functions, particularly user interaction with the product. At this level, C_2: Safety Needs pertains to how user-friendly the product is during use, while C_3: Interaction Needs concerns the effectiveness and efficiency of the functionalities provided. In addition, the reflective level refers to the emotional connection established between the product and the user through interaction, offering psychological value and emotional experience. Therefore, C_4: Emotional Needs is defined as the primary criterion at the reflective level. To ensure consistency and rigor throughout the evaluation process, definitions of all indicators were clearly communicated to the evaluators during the subsequent weighting and assessment phases. This step was essential to maintain the integrity and reliability of the evaluation framework for wooden children's seating design.

Table 1. Design Index Screening Results

Level	First Level Indicator	Secondary Indicators	Mean	Coefficient of Variation	Keep	Secondary Indicators	Mean	Coefficient of Variation	Keep
Visceral level	Visual requirements	Color harmony	0.2478	0.4009	Yes	Elegant Minimalism	0.2842	0.7519	Yes
		Playfulness	0.2139	0.6842	Yes	Integrated structure	0.7341	0.1002	No
		Pattern novelty	0.3333	0.4971	Yes	Refined craftsmanship	0.3426	0.4940	Yes
		Cartoonization	0.7010	0.1178	No	Premium appearance	0.6831	0.1412	No
Behavioral level	Safety requirements	Rounded edges	0.3253	0.6508	Yes	Material sustainability	0.3265	0.7917	Yes
		Seat belt available	0.7214	0.1557	No	Skin-friendly materials	0.2485	0.6788	Yes
		Structural stability	0.2540	0.8413	Yes	Padded edges	0.7229	0.1410	No
		Anti-slip seat	0.7345	0.1318	No	Appropriate dimensions	0.2834	0.6195	Yes
	Interaction requirements	Ease of use	0.4003	0.6489	Yes	Easy assembly	0.3488	0.6440	Yes
		Foldable storage	0.6967	0.1514	No	Easy to clean	0.2668	0.7946	Yes
		Adjustable	0.2456	0.5982	Yes	Playful interaction	0.2886	0.5603	Yes
		Growth adaptability	0.2880	0.4372	Yes	Expandable modules	0.6901	0.1793	No
Reflective level	Emotional requirements	Sense of delight	0.2159	0.7351	Yes	Behavioral guidance	0.3304	0.6248	Yes
		Sense of ownership	0.7544	0.1318	No	Parental involvement	0.3669	0.7205	Yes
		Emotional companionship	0.2651	0.5432	Yes	Enhanced spatial atmosphere	0.6717	0.1240	No
		Trustworthiness	0.3898	0.6081	Yes	Motivational design	0.7420	0.1055	No

Table 2. Criteria Layer Judgment Matrix and Weights

	C_1	C_2	C_3	C_4	AM	GM	Eigen	Weight	Consistency Check
C_1	1	0.3000	2.6469	0.1899	0.1194	0.1159	0.1152	0.1168	λ_{max} =4.1415 I_C =0.0472 R_C =0.0524
C_2	3.3333	1	4.7371	1.5000	0.4079	0.4102	0.4108	0.4097	
C_3	0.3778	0.2111	1	0.1442	0.0627	0.0609	0.0604	0.0614	
C_4	5.2659	0.6667	6.9348	1	0.4099	0.4130	0.4136	0.4122	

Table 3. Sub-criteria Layer Judgment Matrix and Weights

Indicator	Judgment Matrix						AM	GM	Eigen	Weight	Final Weight	Consistency Check
C_{11}	1	0.3976	3.7539	5.0662		2.9367	0.2616	0.2637	0.2620	0.2624	0.0306	
C_{12}	2.5149	1	5.8716	6.7601		5.0523	0.4889	0.4924	0.4946	0.4920	0.0575	λ_{max} =5.1113
C_{13}	0.2664	0.1703	1	1.8559		0.4800	0.0759	0.0747	0.0738	0.0748	0.0087	I_C =0.0278
C_{14}	0.1974	0.1479	0.5388	1		0.3254	0.0506	0.0494	0.0495	0.0499	0.0058	R_C =0.0248
C_{15}	0.3405	0.1979	2.0834	3.0728		1	0.1229	0.1199	0.1200	0.1209	0.0141	
C_{21}	1	1.6431	0.2593	0.2077		0.5254	0.0848	0.0846	0.0845	0.0846	0.0347	
C_{22}	0.6086	1	0.2047	0.1679		0.3289	0.0580	0.0577	0.0578	0.0578	0.0237	λ_{max} =5.0218
C_{23}	3.8570	4.8854	1	0.6186		1.5259	0.2778	0.2778	0.2777	0.2778	0.1138	I_C =0.0055
C_{24}	4.8140	5.9549	1.6164	1		2.8283	0.4139	0.4142	0.4146	0.4143	0.1697	R_C =0.0049
C_{25}	1.9033	3.0406	0.6553	0.3536		1	0.1655	0.1657	0.1654	0.1655	0.0678	
C_{31}	1	6.0039	6.8724	2.5823	5.2198	4.2492	0.4400	0.4334	0.4455	0.4424	0.0272	
C_{32}	0.1666	1	1.6874	0.2449	0.4591	0.4259	0.0598	0.0579	0.0585	0.0591	0.0036	
C_{33}	0.1455	0.5926	1	0.2083	0.3536	0.2424	0.0422	0.0403	0.0414	0.0416	0.0026	λ_{max} =6.1306
C_{34}	0.3872	4.0841	4.8015	1	3.1888	1.7169	0.2228	0.2210	0.2231	0.2237	0.0137	I_C =0.0261
C_{35}	0.1916	2.1781	2.8283	0.3136	1	0.5528	0.0952	0.0911	0.0929	0.0937	0.0058	R_C =0.0211
C_{36}	0.2353	2.3481	4.1261	0.5825	1.8091	1	0.1400	0.1374	0.1386	0.1395	0.0086	
C_{41}	1	4.8015	6.0657	2.8073		3.6443	0.4777	0.4791	0.4813	0.4794	0.1976	
C_{42}	0.2083	1	1.7321	0.3562		0.5154	0.0897	0.0891	0.0885	0.0891	0.0367	λ_{max} =5.0559
C_{43}	0.1649	0.5773	1	0.2693		0.3378	0.0599	0.0593	0.0593	0.0595	0.0245	I_C =0.0140
C_{44}	0.3562	2.8073	3.7132	1		1.6874	0.2208	0.2213	0.2204	0.2208	0.0910	R_C =0.0125
C_{45}	0.2744	1.9402	2.9605	0.5926		1	0.1520	0.1512	0.1504	0.1512	0.0623	

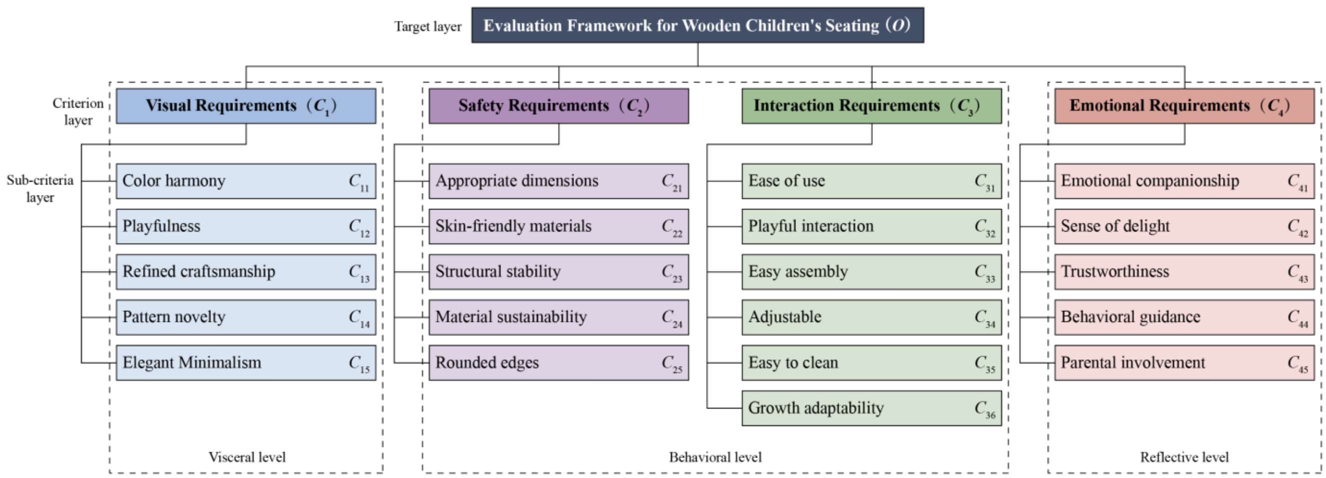

Fig. 5. Evaluation index system for wooden children's seats

Subjective Weight Calculation Based on Improved AHP Method

Using the four criteria and twenty-one sub-criteria as the hierarchy, the authors recruited 30 participants (children's furniture designers, university design professors, parents, and related professionals) to perform pairwise comparisons at each level. These comparisons were used to determine the relative importance among indicators and to construct judgment matrices according to Eq. 1. Subsequently, the weights of the design indicators were calculated using Eqs. 2 through 4, and consistency checks based on the eigenvalue method were conducted using Eqs. 5 and 6. The detailed results are presented in Tables 2 and 3.

Objective Weight Calculation Based on CRITIC Method

To assess the effectiveness of the evaluation index framework for wooden pediatric seating, an expert panel was convened. They screened and selected four representative wooden seating designs for scheme prioritization, then used the resulting evaluations to verify the model's feasibility. Specifically, the authors conducted a market survey, searched ecommerce platforms and brand websites using the keyword "wooden pediatric seating," collected candidates under the "comprehensive," "sales," and "reviews" views. Duplicates were removed. Inclusion criteria required products to be wooden or wood-dominant, to provide clear age-appropriateness information, to exhibit legible structural features, and to include complete text and imagery so that mapping to the evaluation indices was feasible. To avoid brand and copyright concerns, identifying marks were removed from the selected products, retaining only the structural elements necessary for index assessment, and replaced brand names with the labels A, B, C, and D. These four schemes were used to validate the proposed multi-criteria evaluation framework for optimizing children's furniture design, and the specific schemes are presented in Fig. 6.

Scheme A: This scheme features a height-adaptable wooden chair designed to accommodate children's physical growth by offering an adjustable seat and footrest to meet usage needs across different developmental stages. The overall design combines warm wood tones with brightly colored cushions, resulting in a soft color palette and smooth lines that convey a minimalist yet refined visual style. Structurally, large-angle triangular supports are used to ensure stability, while rounded edges and water-based eco-friendly coatings enhance both safety and health. In terms of interaction, the chair allows children to independently climb on and adjust the seat, fostering autonomous learning behavior. Its simple construction also facilitates easy installation and cleaning for parents. On the emotional level, the chair strengthens the bond between child and furniture through a sense of reliability and long-term companionship, further encouraging parent–child interaction and trust development.

Scheme B: This scheme adopts a modular cube-based design that integrates a desk, stool, and storage functions into a single unit, offering children a creative and engaging interactive experience. The overall form is novel, featuring a fully open geometric structure on all four sides and an internal cross-shaped partition, which enhances both recognizability and playfulness, stimulating spatial imagination in children. The product is made from environmentally friendly wood and skin-friendly surface materials. Its one-piece structure is highly resistant to pressure, and all four corners are rounded to ensure safe use. During use, children can flip and reconfigure the unit to serve different functions (learning, play, and storage), while also enabling easy cleaning and organization. From an emotional perspective, the product not only facilitates spaces for parent–child interaction but also provides emotional companionship and comfort through playful engagement. This helps children develop a sense of structure and fosters habits of independence and self-regulation.

Scheme C: This scheme presents a multifunctional children's chair that supports learning, daily living, and developmental transitions. It features a dual-height adjustment and transformable structure, allowing it to function flexibly as a study chair, footstool, or step-up aid. The chair retains the natural color of wood, with a clean and approachable appearance. Crafted using bentwood techniques, it offers a warm tactile quality and a modern aesthetic. Structurally, the chair is designed with a low center of gravity and stable ground contact. Rounded edges enhance safety, and the use of eco-friendly, renewable materials reflects a commitment to sustainability. In terms of interaction, the design encourages children to independently adjust and use the chair, promoting autonomy, while its structure also supports easy handling and storage by caregivers. On the emotional level, the design emphasizes trust and guidance. It not only accompanies the child through daily routines but also empowers them with a sense of participation and achievement in managing their own environment.

Scheme D: This scheme focuses on children's emotional and sensory experiences, featuring a saddle-shaped, curved structure that integrates play, relaxation, and sensory integration training into a rocking chair format. The visual style blends elements of traditional rocking horses with modern minimalist design, combining natural wood tones with soft upholstered padding to achieve a balance of playfulness and elegance. The curved base incorporates an anti-slip design to ensure riding safety, while skin-friendly materials provide a comfortable tactile experience. In terms of interaction, the seat supports various modes of play, such as riding, climbing, and rocking, which stimulate children's curiosity, enhance motor coordination, and invite parent–child participation. The product is suitable for different age groups: the rocking chair form is ideal for children aged 1 to 3, while the chair with backrest accommodates children aged 4 to 8, offering strong adaptability for growth. On the emotional level, the design embodies anthropomorphic care qualities. It offers comfort and emotional reassurance during moments of distress and fosters imaginative engagement through the riding experience. As such, it functions as a companion-like piece of developmental furniture that strengthens emotional bonding throughout a child's growth.

Fig. 6. Wooden children's seating designs

To ensure scientific rigour and validity in data collection, the scoring panel was identical to the AHP participants described above, with a total of 30 members that included children's furniture designers and engineering technicians, university design and engineering faculty, parent users, and practitioners from child-home related industries. Before scoring, all members received standardised definitions of the indicators and exemplar training.

Table 4. Objective Weight Value

Indicator	Variability	Conflict	Information Quantity	Objective Weight
C_{11}	2.637	15.994	42.179	0.0446
C_{12}	6.955	14.546	101.171	0.1069
C_{13}	8.334	3.882	32.354	0.0342
C_{14}	9.137	3.917	35.790	0.0378
C_{15}	8.349	3.899	32.549	0.0344
C_{21}	5.381	10.458	56.277	0.0595
C_{22}	8.715	4.141	36.086	0.0381
C_{23}	8.377	4.047	33.907	0.0358
C_{24}	8.958	3.849	34.485	0.0365
C_{25}	9.294	3.796	35.277	0.0373
C_{31}	9.250	3.898	36.054	0.0381
C_{32}	6.047	11.250	68.033	0.0719
C_{33}	8.605	3.802	32.716	0.0346
C_{34}	8.917	3.798	33.867	0.0358
C_{35}	5.541	7.460	41.337	0.0437
C_{36}	6.988	14.548	101.668	0.1075
C_{41}	2.994	6.300	18.860	0.0199
C_{42}	7.778	4.522	35.168	0.0372
C_{43}	8.188	3.770	30.871	0.0326
C_{44}	4.511	7.159	32.293	0.0341
C_{45}	8.561	8.758	74.978	0.0793

To reduce bias, the materials were de-identified schematics, presented in random order, and all ratings were completed independently without discussion. The researchers then delivered an online briefing and product video demonstration of four wooden pediatric seating units to the evaluators, and asked them to assign scores according to the evaluation indicators. The scoring scale was defined as follows: scores of 30 or below indicated rejection, 31 to 50 indicated relative acceptance, 51 to 60 signified a good rating, 61 to 80 indicated excellence, and 81 to 100 represented outstanding performance. The average of all scores for each indicator was used as the final value. In addition, based on Eq. 7 to Eq. 10, the variability, conflict, information content, and objective weight for each design indicator were calculated. The results are presented in Table 4.

Combination Weight Solution Based on Game Theory Thinking

The application of game theory aims to rationally balance subjective and objective weights, ensuring that the combined weights better reflect real-world conditions and achieve a decision-making equilibrium that maximizes overall utility. After obtaining the subjective and objective weights for the design indicators, a balanced integration of these weights was performed. According to Eq. 11 through Eq. 15, the combined weights were calculated using MATLAB, as shown in Table 5. A visual representation of the weighting results is provided in Fig. 7.

Table 5. Combination Weight of Subjective and Objective

Indicator	Combination Weight	Rank	Indicator	Combination Weight	Rank
C_{11}	0.0352	11	C_{32}	0.0260	15
C_{12}	0.0737	4	C_{33}	0.0131	21
C_{13}	0.0170	19	C_{34}	0.0209	16
C_{14}	0.0163	20	C_{35}	0.0182	18
C_{15}	0.0207	17	C_{36}	0.0410	9
C_{21}	0.0428	8	C_{41}	0.1394	1
C_{22}	0.0284	13	C_{42}	0.0369	10
C_{23}	0.0883	3	C_{43}	0.0272	14
C_{24}	0.1261	2	C_{44}	0.0724	5
C_{25}	0.0578	7	C_{45}	0.0679	6
C_{31}	0.0308	12			

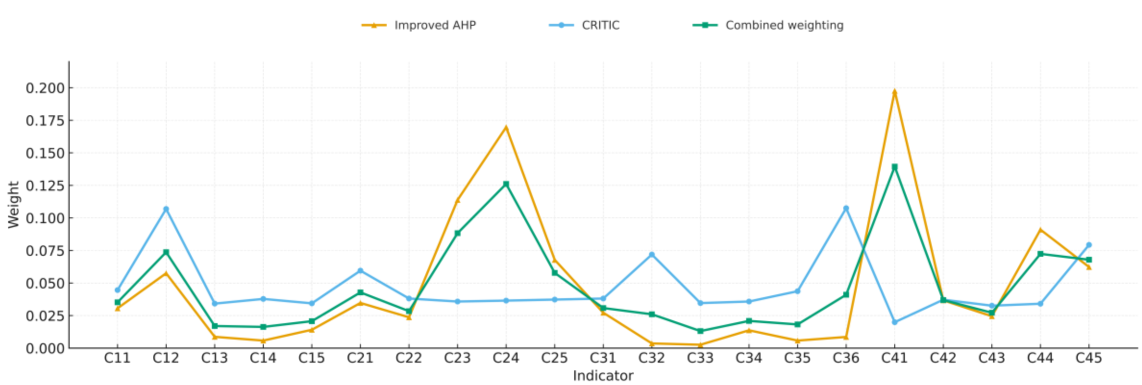

Fig. 7. Comparison results of indicator weight calculation

As illustrated, the weights derived from the improved AHP and CRITIC methods varied considerably. However, after integration through the game-theoretic approach, the combined weight curve tended to moderate, balancing expert subjective judgment with the objective performance of each case. This yielded results that were more scientifically grounded and rational.

The results indicated that the design indicators with the highest weights included emotional companionship (C_{41}), material sustainability (C_{24}), structural stability (C_{23}), playfulness (C_{12}), behavioral guidance (C_{44}), parental involvement (C_{45}), rounded edges (C_{25}), appropriate dimensions (C_{21}), growth adaptability (C_{36}), sense of delight (C_{42}), and color harmony (C_{11}). These indicators represent key considerations in the design process.

Solution Evaluation Based on TOPSIS-RSR

By integrating the improved TOPSIS method with the RSR method, the loss of original data can be minimized, and the evaluation results become more intuitive and credible. This complementary approach enhances the robustness of the assessment and yields results that more closely reflect real-world conditions. Using Eq. 16, the improved TOPSIS computation was performed. During the process, it was observed that the L_i value for Scheme 4 was equal to 0. Although this is mathematically valid, it poses a risk of misinterpretation. Therefore, a minimal positive constant ζ was introduced to adjust the original formula and prevent extreme values. The results are presented in Table 6.

Next, the $\boldsymbol{L_i^{\zeta}}$ values from Table 6 were treated as W values and used in subsequent calculations according to Eq. 17 to Eq. 19. The adjusted $\boldsymbol{L_i^{\zeta}}$ values were taken as the dependent variable, and the corresponding *Probit* values as the independent variable, for regression fitting. The resulting regression equation was: $\boldsymbol{L_i^{\zeta}} = -0.0551+0.0141 Probit$. The coefficient of determination was R^2=0.9897, with an F-value of 192.5348 and a P-value of 0.0052 (P<0.01), indicating a statistically significant linear relationship between the two variables. Based on the principle of optimal classification (Yin *et al*. 2025), the *Probit* values were used to compute the estimated W values via the regression equation, which were then used for classification and ranking. The results are shown in Table 7.

The improved TOPSIS method enables the ranking of alternatives under multi-criteria evaluation, while the RSR method transforms the comprehensive scores from improved TOPSIS into rank values and cumulative frequencies, subsequently mapping them into a normally distributed space using *Probit* transformation. The combined strengths of these two methods have been demonstrated in prior studies across various disciplines (Yuan *et al*. 2024), though their application within the field of design remains largely unexplored.

The integrated TOPSIS–RSR evaluation model preserves both the original data characteristics and the advantages of rank-based analysis, balancing the scientific rigor of quantitative ranking with the intuitive clarity of ordinal classification. This provides more operable and actionable decision-making support for comprehensive evaluations. Based on the analysis above and the resulting data,

Scheme D emerges as the optimal solution, followed by Scheme B, with Scheme A ranked third. Schemes A, B, and D all fall within the first-tier classification, whereas Scheme C ranks last and is classified in the second tier.

Table 6. Improved TOPSIS Calculation Results

Scheme	D_i^+	D_i^-	L_i^ζ	Rank
A	0.0191	0.0117	0.0204	3
B	0.0103	0.0195	0.0087	2
C	0.0272	0.0038	0.0317	4
D	0.0049	0.0261	0.0001	1

Table 7. RSR Value Distribution and Results

Scheme	W（L_i^ζ）	Frequency	Cumulative Frequency	Downward Cumulative Frequency	*Probit*	*W* Estimate	Rank	Classification
D	0.0001	1	1	0.1250	3.8497	-0.0010	1	1
B	0.0087	1	2	0.3750	4.6814	0.0107	2	1
A	0.0204	1	3	0.6250	5.3186	0.0197	3	1
C	0.0317	1	4	0.8750	6.1503	0.0314	4	2

Table 8. Comparison of Common Methods

Scheme	FCE	Rank	GRA	Rank	EWM	Rank	TOPSIS	Rank	RSR	Rank
A	0.3240	3	0.4628	3	0.2327	3	0.3792	3	0.5392	3
B	0.6068	2	0.6116	2	0.5841	2	0.6538	2	0.6553	2
C	0.0805	4	0.3673	4	0.1030	4	0.1229	4	0.3587	4
D	0.9173	1	0.9167	1	0.9236	1	0.8430	1	0.9471	1

Comparative Test

To verify the validity of the evaluation results and the effectiveness of the proposed model, a comparative analysis was conducted using several established methods: traditional TOPSIS, weighted RSR, and commonly used evaluation approaches in design research, including FCE, GRA, and EWM (Liu and Yi 2023). The results are presented in Table 8. In this comparison, the FCE method reflects normalized scores; traditional TOPSIS retains the relative closeness coefficient; and weighted RSR incorporates the combined indicator weights into the rank sum ratio. The findings show that multiple evaluation methods consistently identified Scheme D as the optimal solution, which further supports the applicability and effectiveness of the TOPSIS–RSR method in evaluating wooden children's seating products.

In this study, the improved AHP and CRITIC methods were employed to determine the subjective and objective weights of design indicators for wooden children's seating. Game theory was then introduced to integrate these weights, effectively reducing the subjectivity associated with individual indicators. Additionally, the TOPSIS–RSR ranking approach was applied, replacing the L_i values with W values. This integration combines the relative distance concept of TOPSIS with the non-parametric ranking capability of the RSR method, thereby mitigating the impact of outliers and enhancing the robustness and interpretability of the comprehensive evaluation. As a result, the final outcomes are more objective, rational, and precise.

Discussion

Novel features

Taking wooden children's seating as a case study, this research aimed to establish a scientific, objective, and systematic evaluation and optimization framework for children's furniture design, with the goal of enhancing the rationality of product development decisions and improving user satisfaction. Through the integrated application of the improved AHP, CRITIC, and TOPSIS–RSR methods, the proposed multi-criteria evaluation framework effectively quantifies the relative importance of user needs and successfully identifies the design scheme with the best overall performance. This research pathway significantly enhances the capacity to identify and integrate multidimensional user requirements in the design of wooden children's seating. Moreover, it provides a replicable, scientifically grounded decision-making model that can be extended to the design and development of other children's furniture products.

In constructing the evaluation index system for wooden children's seating, authentic user needs were extracted from online reviews and refined through expert panel discussions and coefficient of variation analysis. This process yielded 21 specific indicators, categorized into four primary dimensions: visual, safety, interaction, and emotional needs. These dimensions were mapped onto Norman's three levels of emotional design theory and Jordan's hierarchy of product requirements. The established system not only addresses both functional and psychological user needs but also demonstrates a nuanced understanding of the evolving demands associated with different stages of child development. This approach integrates semantic mining with theoretical frameworks and represents a novel contribution to research on children's furniture design, addressing the widely noted disconnect between functional and emotional considerations (Li and Wang 2024).

After constructing the design indicator system for wooden children's seating, multiple models were integrated to assess and rank the importance of each design criterion.

Specifically, this study addressed the strong subjectivity inherent in the traditional AHP method by employing an improved version of AHP and incorporating the CRITIC method to enhance the objectivity of data-driven evaluation. Furthermore, game-theoretic reasoning was applied to optimize the integration of subjective and objective weights, resulting in more robust composite weighting outcomes. Compared with studies such as Yu *et al*. (2023, 2024), which rely primarily on single weighting methods, the present methodological framework offers greater objectivity, balance, and adaptability. This is particularly advantageous in the context of complex, multi-dimensional indicator systems like those involved in wooden children's seating design, where the management of uncertainty requires a more resilient analytical approach.

Finally, in the process of design scheme optimization, an improved TOPSIS method combined with the RSR rank-based analysis was employed to overcome limitations of the traditional relative closeness index—specifically, its tendency toward distortion and inability to distinguish among closely ranked alternatives. This approach enabled accurate ranking and grading of wooden children's seating design solutions. In comparison with the single multi-attribute decision-making methods used by Wang and Zhao (2024) and Struzikiewicz *et al*. (2024) in evaluating children's furniture design, the proposed TOPSIS–RSR model demonstrates superior explanatory power and practical applicability. In particular, for classification purposes, the integration of *Probit* regression endows the evaluation results with statistical significance, substantially enhancing the interpretability and visual clarity of decision outcomes.

In the weight analysis of design indicators for wooden children's seating, indicators such as "emotional companionship," "behavioral guidance," and "parental involvement" ranked among the most important. This result not only validates and reinforces the significance of emotional factors in children's furniture design (Ginsburg 2007), but it also aligns with the characteristics of children's cognitive development and growth patterns (Piaget and Cook 1952). Incorporating emotional companionship into children's furniture design plays a vital role in supporting development and shaping behavior (Miao *et al*. 2024). This finding also suggests that children's furniture should not merely function as utilitarian objects, but rather serve as a medium for fostering emotional bonds between parent and child, and as a catalyst for the development of a child's personality.

Based on the analysis of indicator weights and design scheme rankings, the following specific design strategies are proposed for wooden children's seating: First, wooden children's seating should emphasize parent–child integration and emotional value, reinforcing the social and interactive functions of furniture. These products should not merely serve as functional physical supports, but also act as active participants in building parent–child relationships and fostering children's social cognition. In this regard, children's furniture must shift from simply "meeting functional needs" to "co-constructing emotional value," thereby expanding its role in supporting psychological development. Second, wooden children's seating should be grounded in safety and health while integrating growth adaptability and behavioral guidance. Design indicators such as "structural stability," "rounded edges," "material sustainability," and "adaptability for growth" were identified as having relatively high importance. These findings align with the research of Struzikiewicz *et al*. (2024) and Zhao and Xu (2023). Accordingly, eco-friendly, low-formaldehyde materials should be employed, and anti-tip structural optimizations implemented to ensure physical safety. At the same time, modular configurations and multi-stage dimension adjustments should be incorporated to enable continuous use from early childhood through school age, supporting the formation of behavioral habits and adapting to diverse usage scenarios. Finally, wooden children's furniture should enhance playfulness and visual appeal to stimulate children's willingness to engage voluntarily. The prominence of indicators such as "playfulness," "sense of delight," and "color harmony" underscores the importance of contextual beauty and visual experience in supporting children's cognitive participation. Design solutions should integrate biomorphic forms, vibrant color schemes, and playful elements to create a product language that encourages exploration and emotional engagement, thereby increasing both usage interest and emotional investment.

From an application-oriented perspective, the integrated evaluation framework proposed in this study holds considerable value for broader implementation. On one hand, design practitioners can utilize this approach to identify the priority of user needs and achieve precise functional alignment in wooden children's seating configurations. On the other hand, manufacturers can apply the model to optimize their research and development processes, facilitating a shift from intuition-driven decisions to systematic, data-informed strategies—ultimately enhancing product-market fit and user satisfaction. Moreover, the proposed framework also possesses theoretical transferability and can be extended to other children's furniture design contexts that involve multi-criteria trade-offs.

Limitations

Despite the methodological advancements and empirical validations achieved in this study, several limitations remain. The study focused exclusively on wooden children's seating as a case, and the selected design schemes were limited to that category, which constrains the generalizability of the findings across the full spectrum of children's furniture applications. Although the user-review dataset offered broad coverage, e-commerce reviews, as unstructured text, are inherently subjective and may be influenced by emotional fluctuations, personal preferences, and other non-rational factors. Third, while the proposed evaluation index system integrated multiple perspectives, it had not yet fully addressed the adaptability to cultural differences and variations in family structures. Fourth, the model had not yet parameterized the pronounced heterogeneity across pediatric ages and developmental stages. The current dataset lacked consistent age labels, and safety standards and anthropometric parameters differ by age group. Accordingly, to ensure interpretability and reproducibility, the model can be regarded as a baseline assessment and provide clear indicator weights and scoring rules. Practitioners can then recalibrate and screen within existing age bands or height based stratification schemes, rather than introducing new parameters when the data support is insufficient. Finally, although the evaluation model benefited from integrated subjective–objective weighting optimization, the relatively limited dataset may affect the universality of the results. Future research could incorporate machine learning techniques to conduct deeper semantic analysis of emotional language, extend the framework to other categories of furniture, and utilize long-term user tracking data to assess the stability and scalability of the proposed model. Additionally, in future research the authors will develop a decision support prototype tailored to different ages. The prototype will allow users to input age, usage context, budget, and other relevant information. Subject to hard constraints, the system will return one or two candidate products, and it will present interpretable scoring rationales together with a clear report of constraint satisfaction.

Summary

In summary, this study integrated several multi-criteria decision-making models to construct a user-centered design pathway for children's furniture. The proposed framework was grounded in user semantic mining, the fusion of subjective and objective weighting, and precise scheme evaluation. Using wooden children's seating as a case study, empirical validation of the model was conducted. The results significantly advanced the systematization and data-driven development of decision-making in children's furniture design, while also expanding the theoretical scope and practical depth of research in this domain. In the future, this model can be extended to other areas of children's furniture design, and further refined through real-world user testing and iterative product feedback, thereby contributing to the continuous development of a robust theoretical and practical system for the scientific design of children's furniture. Future research will consider incorporating advanced natural language processing techniques, such as deep learning, to enable higher-order modeling of users' emotional semantics. In addition, future research will extend the proposed model to a broader range of children's furniture categories and evaluate its long-term stability and predictive capabilities.

CONCLUSIONS

1. This study developed a multi-criteria decision-making framework for optimizing children's furniture design by integrating user semantic mining, subjective–objective weight fusion, and comprehensive evaluation analysis. Specifically, a large volume of online review data on wooden children's seating was collected and processed. By employing Jieba word segmentation and sentiment analysis, authentic user needs were extracted, and the coefficient of variation method was applied to construct a multi-dimensional design indicator system. Subsequently, an improved analytic hierarchy process (AHP) method and the Criteria Importance Through Intercriteria Correlation (CRITIC) method were introduced to assign subjective and objective weights, respectively. These were then integrated using game theory. Finally, the TOPSIS–RSR model was applied to rank and classify the design schemes. The empirical results validated the adaptability and scientific validity of the proposed model.
2. An empirical investigation was conducted using wooden children's seating as a representative case. The results identified the most heavily weighted design indicators as emotional companionship (C_{41}), material sustainability (C_{24}), structural stability (C_{23}), playfulness (C_{12}), behavioral guidance (C_{44}), parental involvement (C_{45}), rounded edges (C_{25}), appropriate dimensions (C_{21}), growth adaptability (C_{36}), sense of delight (C_{42}), and color harmony (C_{11}). These indicators represent key considerations in the design process. Among the four evaluated design schemes, Scheme D was determined to be the most optimal. Based on the high-priority indicators and the outcome of the scheme evaluation, three specific design strategies for wooden children's seating were proposed: (1) focus on parent–child integration and emotional value to enhance the social-interaction function of furniture; (2) ensure safety and health as the foundation, while integrating growth adaptability and functional guidance; and (3) enhance playfulness and visual appeal to stimulate children's willingness to actively engage with the product.

3. The findings indicate that the proposed design framework not only effectively addresses the high subjectivity and lack of quantitative decision logic commonly found in traditional design processes, but it also significantly enhances the systematization, scientific rigor, and practical orientation of children's furniture design. At the theoretical level, this study innovatively integrates design methodologies with decision science tools, thereby addressing the limitations of systematic evaluation methods in the field of children's furniture. At the practical level, the model demonstrates strong transferability and operability, providing designers and manufacturers with a reliable quantitative basis for decision-making. This facilitates the transition from experience-based to data-driven design in children's furniture, further improving product-market alignment and user satisfaction.
4. In the evolving landscape of children's furniture design methodologies, the shift from experience-based approaches to data-driven strategies has become an established trend. Moving further toward intelligent and precision-oriented design centered on cognitive and emotional needs represents a critical breakthrough for advancing the field. Although this study has achieved notable progress in integrating multi-source evaluation methods and modeling user semantic input, certain limitations remain.

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APPENDIX

```
import pandas as pd
import time
import requests
import logging
from datetime import datetime

# Configure logging
logging.basicConfig(
    level=logging.INFO,
    format='%(asctime)s - %(levelname)s - %(message)s',
    handlers=[
        logging.FileHandler('jd_comment_crawler.log', encoding='utf-8'),
        logging.StreamHandler()
    ]
)
logger = logging.getLogger(__name__)

# Proxy settings
proxyHost = "tps732.kdlapi.com"
proxyPort = "15818"
proxyUser = "t14664251268147"
proxyPass = "4ztigay0"
proxyMeta = "http://%(user)s:%(pass)s@%(host)s:%(port)s" % {
    "host": proxyHost,
    "port": proxyPort,
    "user": proxyUser,
    "pass": proxyPass,
}
proxies = {
    "http": proxyMeta,
    "https": proxyMeta,
}

# Request headers
headers = {
    'User-Agent': 'Mozilla/5.0 (Windows NT 10.0; WOW64) AppleWebKit/537.36
(KHTML, like Gecko) Chrome/107.0.0.0 Safari/537.36'
}

def fetch_comments(page):
    """
    Fetch comments for a given page

    Args:
        page (int): Page index
```

```
    Returns:
        list: List of comments, or None on failure
    """
    try:
        url =
f'https://club.jd.com/comment/productPageComments.action?productId=3081867&score
=1&sortType=5&page={page}&pageSize=10&isShadowSku=0&rid=0&fold=1'
        response = requests.get(url=url, headers=headers, timeout=10, proxies=proxies)
        response.raise_for_status()  # Check whether the request succeeded

        # Parse JSON payload
        data = response.json()
        if 'comments' not in data:
            logger.warning(f"No comments found on page {page}")
            return None

        return data['comments']
    except requests.exceptions.RequestException as e:
        logger.error(f"Error while requesting page {page}: {e}")
        return None
    except ValueError as e:
        logger.error(f"Error parsing JSON for page {page}: {e}")
        return None

def process_comments(comments):
    """
    Process comments and extract fields

    Args:
        comments (list): List of raw comments

    Returns:
        list: List of processed comments
    """
    processed_data = []
    for comment in comments:
        try:
            data = {
                'content': comment.get('content', ''),
                'created_at': comment.get('creationTime', ''),
                'score': comment.get('score', ''),
                'nickname': comment.get('nickname', '')
            }
            processed_data.append(data)
        except KeyError as e:
            logger.warning(f"Missing required fields in comment: {e}")
            continue
```

```
    return processed_data

def main():
    """
    Main entry that orchestrates the crawl
    """
    logger.info("Start crawling JD.com product negative reviews")
    start_time = time.time()

    all_comments = []
    failed_pages = []

    # First pass
    logger.info("Starting the first pass")
    for page in range(100):
        logger.info(f"Fetching page {page}")

        comments = fetch_comments(page)
        if comments is None:
            failed_pages.append(page)
            continue

        processed_comments = process_comments(comments)
        all_comments.extend(processed_comments)

        # Add delay to avoid sending requests too frequently
        time.sleep(0.5)

    # Retry failed pages
    if failed_pages:
        logger.info(f"Retrying {len(failed_pages)} failed pages")
        retry_failed = []

        for page in failed_pages:
            logger.info(f"Retrying page {page}")

            comments = fetch_comments(page)
            if comments is None:
                retry_failed.append(page)
                continue

            processed_comments = process_comments(comments)
            all_comments.extend(processed_comments)

            # Add delay
            time.sleep(0.5)

        if retry_failed:
```

```
            logger.warning(f"The following pages still failed after retry: {retry_failed}")

    # Save to Excel
    if all_comments:
        try:
            df = pd.DataFrame(all_comments)
            filename =
f'children_wooden_chair_negative_reviews_{datetime.now().strftime("%Y%m%d_%H
%M%S")}.xlsx'
            df.to_excel(filename, index=None)
            logger.info(f"Successfully saved {len(all_comments)} comments to {filename}")
        except Exception as e:
            logger.error(f"Error when saving to Excel: {e}")
    else:
        logger.warning("No comments were retrieved")

    end_time = time.time()
    logger.info(f"Crawling finished, total elapsed time {end_time - start_time:.2f}
seconds")

if __name__ == "__main__":
    main()
```