Sustainable Wooden Toy Design for Children Based on the Kano-AHP-VIKOR Integrated Approach

Xiaoqin Cao, Tiantian Sun, Yuanhao Ding, and Fangting Xu *

With the intensification of global environmental challenges and the rising environmental awareness among parents, traditional children's toys face growing criticisms regarding excessive resource consumption, poor recyclability, and inadequate sustainability. Wooden toys, in particular, encounter new obstacles in material innovation, structural optimization, and functional upgrading. To address the conflicting requirements of functionality, safety, and sustainability in wooden toy design, this study proposes a quantitative decision-making framework integrating the Kano model, Analytic Hierarchy Process (AHP), and VIKOR method. Unlike traditional design approaches that rely on intuition, this study first quantified user attributes through the Kano model, identifying "material traceability" as a high-priority "Attractive" attribute alongside "Must-be" safety requirements. AHP is then utilized to construct a hierarchical weighting system, revealing a "Safety-First, Ecology-Second" preference structure among stakeholders (Weights: Safety 0.482 > Ecology 0.273). Finally, the VIKOR method was used to rank five alternative schemes, identifying a modular furniture-toy combination as the compromise optimal solution due to its superior performance in high-weight indicators. This research provides a verifiable pathway for translating vague sustainable concepts into actionable design indicators.

DOI: 10.15376/biores.21.2.3469-3491

Keywords: Sustainable design; Wooden children's toys; Kano model; Analytic Hierarchy Process (AHP); VIKOR method

*Contact information: Hexiangning College of Art and Design, Zhongkai University of Agriculture and Engineering, Guangzhou, 510000 China; *Corresponding author: 1536558712@qq.com*

INTRODUCTION

As global ecological concerns escalate and parental environmental consciousness advances, the toy industry faces a paradigm shift. Traditional children's toys are increasingly criticized for their high resource consumption, excessive packaging, and poor recyclability. Public attention to sustainable consumption has surged, as every decision made during product development exerts direct social and environmental impacts on humanity and the planet (Watkins *et al.* 2021). As consumer goods integrating entertainment and education, toy design not only influences children's safety and developmental experiences but also reflects the environmental awareness of families and society. Incorporating sustainability into toy design can both drive industry progress and contribute to broader social advancement. Toy design, as a vital component of product design, holds emotional value, stimulates creativity, and adapts to evolving consumer demands (Chen *et al.* 2025). However, developing sustainable solutions remains challenging, requiring a balance between environmental goals, functionality, economics, aesthetics, and consumer acceptance (Cao *et al.* 2021). Currently, most toys on the market suffer from non-degradable materials, short structural lifespans, and excessive packaging, leading to resource waste and environmental burdens. Additionally, lifecycle assessment (LCA) studies have demonstrated significant environmental variations across toy categories and usage stages, underscoring the necessity of design optimization throughout the "material-manufacturing-use-disposal" lifecycle (Levesque *et al.* 2022). This contradiction highlights the urgency and practical significance of researching sustainable children's toy design.

Traditional design methods often prioritize aesthetic or functional innovation while neglecting the hierarchical classification and quantitative analysis of genuine user needs, making it difficult to achieve multi-objective optimization. Thus, there is a pressing need to introduce scientific user demand analysis and multi-criteria decision-making (MCDM) methods to establish a systematic and operable sustainable design system. In recent years, the Kano model has been widely used to identify and categorize user needs by classifying them into Must-be, One-dimensional, and Attractive attributes, providing clear directions for product innovation. The Analytic Hierarchy Process (AHP) enables quantitative importance evaluation of different demand categories based on expert judgment, establishing a subjective weight system with consistency verification to enhance the scientific rigor and transparency of demand prioritization. Building on this, the VIKOR method ("višekriterijumsko kompromisno rangiranje") — a typical compromise ranking tool— synthesizes the balance between multiple evaluation indicators and user satisfaction to identify solutions closest to the ideal, making it particularly suitable for complex scenarios involving conflicting objectives such as sustainability, functionality, and emotional experience.

In summary, this study constructs an integrated evaluation and optimization model based on Kano-AHP-VIKOR, forming a complete closed-loop decision-making process. Instead of applying "green" labels based on general assumptions, this study uses the framework to quantitatively filter design elements, ensuring that final features are derived directly from stakeholder priorities. The research aims to: (1) quantitatively identify the hierarchical demand characteristics of stakeholders regarding wooden toys; (2) establish a weight system that reflects the specific trade-offs between safety, education, and sustainability; and (3) apply the VIKOR method to select a design scheme that minimizes the regret value between conflicting objectives.

LITERATURE REVIEW

Sustainable Toy Design

Recent research on sustainable design has shifted from single-point material focus to integrated studies encompassing materials, structures, green ecology, interaction, and services. Similarly, children's toy design research increasingly emphasizes multi-dimensional sustainability integration. For instance, Tu *et al.* (2022) centered on the product lifecycle concept, extracting eight key decision factors for green toy design through literature analysis, expert interviews, consumer surveys, and data research, providing references for designers and enterprises while supporting sustainable design research in product lifecycle and toy development. Chen *et al.* (2025) aligned sustainability with the UN Sustainable Development Goals (SDGs), reviewing the theory and practice of sustainable toy design, focusing on materials and manufacturing processes, and exploring sustainability's impact on product value, lifespan, and social benefits, highlighting its multi-faceted significance and industry trends. Ferreira *et al.* (2024) addressed the lack of assistive toys for blind and visually impaired children with motor developmental delays, developing "bumpi"—a sustainable toy made from aggregated cork— to promote motor skill development in 1 to 5-year-olds through tactile and auditory stimulation. Two rounds of prototype testing validated its functionality, while the study discussed the roles of materials, design, and toys in children's development. Takato and Shirayama (2012) used the bamboo flying toy "Taketombo" to implement engineering education for a sustainable society, integrating mechanical engineering theories with Project-Based Learning (PBL) to stimulate student interest and foster sustainable design and practical capabilities.

Despite these advancements, existing research still faces limitations, including inadequate lifecycle optimization, insufficient quantification of hierarchical user needs, and low integration of subjective and objective evaluation systems. Additionally, toys require improvements in material degradability, structural durability, and minimal packaging. Future research should focus on systematic assessments of materials' environmental impacts and strengthening of the application of resource recyclability and eco-friendliness in design. Consequently, this study selected wood, bamboo, and other degradable materials as primary media for sustainable children's toy design, aiming to achieve organic unification between functionality, emotional value, and environmental sustainability, and providing a practical pathway for constructing a green design system.

Integrated Design Evaluation Models Based on Multi-criteria Decision-making

With the deepening of sustainable design concepts, scientifically identifying ambiguous user needs and achieving comprehensive optimization of design schemes under multiple conflicting criteria have become focal points in academic research. Miao *et al.* (2025) combined interviews with the Kano, AHP, and Quality Function Deployment (QFD) methods to extract and transform parent-child interactive literacy needs into design elements, developing interlocking literacy toys. A controlled experiment with 10 children aged 3 to 6 years old validated superior literacy efficiency, interest, and parent-child interaction, while acknowledging research limitations and offering insights for children's product design. Miao *et al.* (2024) addressed toy storage in three kindergarten areas, identifying needs through interviews and grounded theory, determining optimization goals (improving storage efficiency) *via* AHP, and verifying the effectiveness of color zoning through eye-tracking experiments with 30 children aged 3 to 6 (optimal layout: 3-13). The final optimized storage cabinets enhanced children's independent storage efficiency and fostered classification cognition. Li and Xue (2023) integrated the Kano model, AHP, and Function-Behaviour-Structure (FBS) model to construct a scientific design framework for children's educational toys. Through identifying needs and attributes, calculating demand weights, and deriving mapping relationships, they developed a multi-sensory educational toy and supporting interface, with user satisfaction surveys validating the design process's effectiveness. This work provides solutions for accurately capturing children's needs and responding to the growing trend of family investment in early education. Wang *et al.* (2023) extracted common design elements from existing children's interactive products, conducted quantitative and qualitative analysis of user needs using the Kano model, clarified consumer-preferred design principles and attributes, and proposed relevant design strategies and innovative ideas to assist designers in making comprehensive decisions and enhancing product competitiveness. These studies demonstrate that multi-model integration effectively addresses "ambiguous needs and complex evaluation" in children's products, providing a quantifiable decision-making pathway for toy design.

In the specific field of children's toys, sustainability assessment has expanded from mere material eco-friendliness to comprehensive lifecycle considerations. Yamane and Kayo (2025) argued that toy LCA should cover the entire lifecycle—production, consumption, and disposal—emphasizing the importance of evidence-based environmental impact assessment. Meanwhile, Kovačič Lukman *et al.* (2021) integrated circular economy principles into toy case studies, verifying that material substitution and structural optimization can significantly reduce carbon footprints. Despite progress in green material application (Xu *et al.* 2024) and multi-objective optimization (Brioso and Calderon-Hernandez 2023), quantitative decision-making research on balancing the "ecological-educational-emotional" multi-dimensional values of wooden toys remains scarce. To address this gap, the Kano-AHP-VIKOR model proposed in this study aims to complement existing research's limitations in integrating subjective weights and compromise ranking. Through leveraging the VIKOR method to balance maximum group benefit and minimum individual regret, this study provides a scientific decision-making basis for developing environmentally friendly and educationally valuable wooden children's toys.

METHODOLOGY

Proposed Framework

This study aimed to develop a systematic evaluation and optimization method for sustainable wooden toy design, achieving multi-objective balance between functionality, educational value, and sustainability. The integrated analytical framework combined the Kano model, AHP, and VIKOR method, progressing from user demand identification to scheme selection, and gradually realizing the integration of subjective weights and multi-criteria decision optimization. The research framework included four key stages: user demand acquisition and classification, determination of demand indicator weights, optimization and selection of design schemes, and result validation (Fig. 1):

(1) *User Demand Acquisition and Classification*: To determine the initial user demand items, this study employed a combined approach of field research, semi-structured interviews, and questionnaire surveys distributed to parents, kindergarten teachers, and toy designers. Subsequently, the satisfaction levels for these demands were analyzed using the KANO model, classifying them into Must-be (M), One-dimensional (O), and Attractive (A) attributes. This process established a hierarchical user demand indicator system.

(2) *Calculation of Comprehensive Demand Weights*: Following demand classification, AHP was used to conduct subjective evaluation of demand indicator importance. Experts in product design, early childhood education, and sustainable design were invited to perform pairwise comparisons of indicators, construct judgment matrices, and obtain subjective weights through consistency verification.

(3) *Optimization and Selection of Design Schemes*: The development of five sustainable wooden toy design schemes are guided based on demand weight rankings. The VIKOR method was employed for multi-criteria comprehensive evaluation of alternative schemes, calculating the comprehensive utility value (S), maximum regret value (R), and comprehensive index (Q) to measure proximity to the ideal solution. The optimal design scheme based on ranking results was identified, and further optimization

directions considering sustainability, manufacturing feasibility, and emotional interaction were proposed. This stage achieved a compromise between user satisfaction and environmental performance.

(4) *User Feedback Assessment*: Instead of empirical environmental testing (*e.g*., LCA), questionnaires were distributed to the target group to assess their subjective satisfaction with the optimized scheme. This step verified whether the design effectively translated the high-priority 'Sustainable' and 'Safety' weights into user-perceived product features.

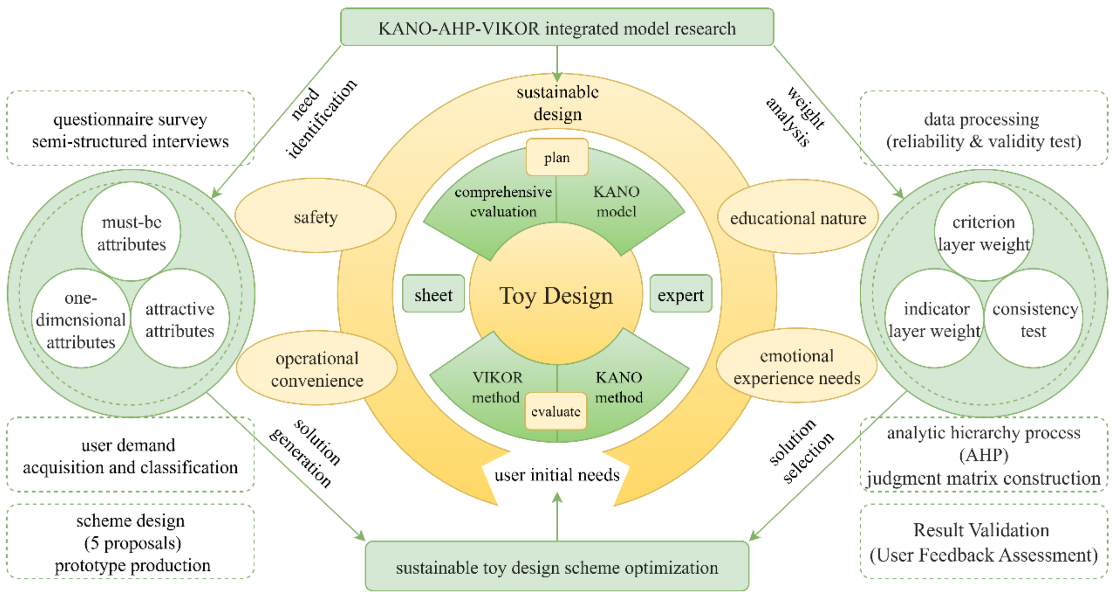

Fig. 1. Flowchart of the KANO-AHP-VIKOR integrated research framework

Kano Model

The Kano model is a qualitative analysis tool (Mikulic and Prebezac 2011) that is primarily used to analyze differentiated user needs in the early stages of product design. Proposed by Japanese scholar Noriaki Kano, the model classifies product attributes through two-dimensional analysis of user satisfaction and function implementation (Fig. 2). Each demand element is categorized using the Kano classification judgment matrix, resulting in six types: Must-be (M), One-dimensional (O), Attractive (A), Indifferent (I), Reverse (R), and Questionable (Q) attributes (Table 1). The specific definitions for these attributes are:

Must-be attributes (M): Basic requirements. Their fulfillment does not significantly increase satisfaction, but their absence causes extreme dissatisfaction.

One-dimensional attributes (O): Performance attributes. User satisfaction is linearly proportional to the degree of fulfillment; the higher the fulfillment, the higher the satisfaction.

Attractive attributes (A): Delighter attributes that exceed user expectations. Their presence significantly boosts satisfaction, while their absence does not cause dissatisfaction.

Indifferent attributes (I): Users do not care whether these features are present or not; they have no impact on satisfaction.

Reverse attributes (R): These attributes result in dissatisfaction when present and satisfaction when absent.

Questionable attributes (Q): Indicates a contradiction in the user's response (*e.g.*, liking both presence and absence), suggesting a misunderstanding or error.

The specific implementation and analytical procedure are outlined as follows:

(1) *Demand Classification*: Respondents' answers are combined to positive and negative questions for each attribute and determine the demand type using the KANO classification matrix (Table 1).

Table 1. KANO Model Classification Judgment Matrix

Product Requirement		When the requirement is not met				
		Like	Must-have	Neutral	Tolerable	Dislike
When the requirement is met	Like	*Q*	*A*	*A*	*A*	*O*
	Must-have	*R*	*I*	*I*	*I*	*M*
	Neutral	*R*	*I*	*I*	*I*	*M*
	Tolerable	*R*	*I*	*I*	*I*	*M*
	Dislike	*R*	*R*	*R*	*R*	*Q*
M = Must-be attributes; O = One-dimensional attributes; A = Attractive attributes; I = Indifferent attributes; R = Reverse attributes; Q = Questionable results						

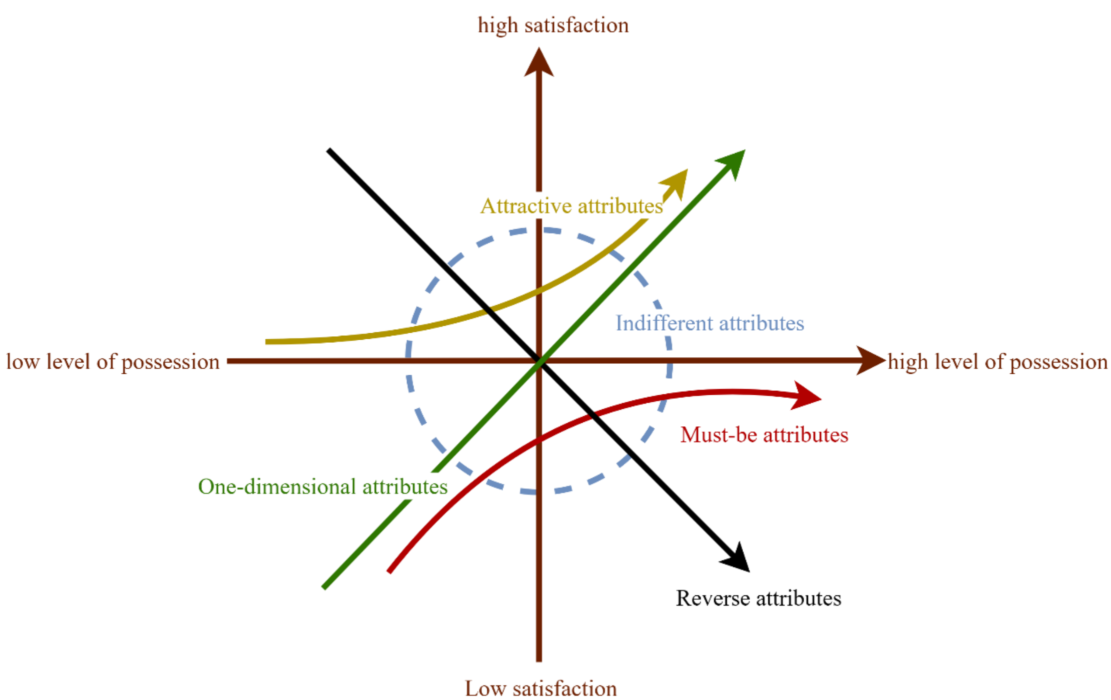

Fig. 2. KANO model diagram

(2) *Calculation of Satisfaction Coefficients*: To intuitively prioritize needs, the Better and Worse coefficients are calculated using the following formulas,

$$\text{Better} = \frac{A + O}{A + O + M + I} \tag{1}$$

$$\text{Worse} = -\frac{O + M}{A + O + M + I} \tag{2}$$

where *A* is the Attractive requirements, *O* = One-dimensional requirements, *M* is the Must-be requirements, *I* is the Indifferent requirements. The Better coefficient ranges from 0 to 1, with higher values indicating greater sensitivity and priority. The Worse coefficient ranges from -1 to 0, with lower values (more negative) indicating higher sensitivity and importance.

(3) *Determination of Demand Importance and Matrix Construction*: Each demand is mapped on a two-dimensional coordinate system based on calculated coefficients. Demands with high Better values and low absolute Worse values are typically classified as "Attractive," with significant potential to enhance satisfaction. Those with high Better values and high absolute Worse values are "One-dimensional" and require focused attention. Demands with high absolute Worse values are mostly "Must-be," representing basic requirements that must be met in design. This process yields the hierarchical distribution and priority ranking of user needs.

AHP

Proposed by Saaty (1987), AHP is an MCDM method that structures complex problems hierarchically and quantifies indicator weights through subjective judgment. Its advantage lies in converting subjective evaluations into formal mathematical models, thereby providing clear priority rankings in multi-dimensional design evaluation. For sustainable wooden toy design, AHP effectively integrates opinions from designers, parents, and educational experts, establishing a hierarchical structure among functional, educational, emotional, and sustainable needs to form a quantifiable weight system. The steps are as follows:

(1) *Construct Hierarchical Structure Model*: Based on demand types identified by the KANO model, divide children's toy needs into three levels: target layer, criterion layer, and indicator layer.

(2) *Construct Judgment Matrix*: This is the core step of AHP. Decision-makers evaluate the relative importance of each pair of criteria using expert experience, employing a 1 to 9 scale (Table 2). For n criteria, the judgment matrix A is an $n \times n$ matrix where a_{ij} represents the relative importance of criterion i compared to criterion j. For example, if criterion 1 is slightly more important than criterion 2 (scale 3), then $a_{12} = 3$ and $a_{21} = 1/3$. The general form of the judgment matrix is:

$$A = \begin{pmatrix} 1 & a_{12} & a_{13} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & a_{23} & \cdots & a_{2n} \\ \frac{1}{a_{13}} & \frac{1}{a_{23}} & 1 & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \frac{1}{a_{3n}} & \cdots & 1 \end{pmatrix} \tag{3}$$

(3) *Calculate Weights*: AHP uses eigenvalue decomposition to calculate criterion weights:

Eigenvalue and Eigenvector Calculation: Solve the eigenvalue problem for the judgment matrix A:

$$A \cdot \mathrm{w} = \lambda_{max} \cdot \mathrm{w} \tag{4}$$

where $\lambda_{\max}$ is the maximum eigenvalue and w is the corresponding eigenvector (weight vector).

Normalization: Normalize the eigenvector w to ensure the sum of weights equals 1:

$$w_i = \frac{w_i'}{\sum_{i=1}^{n} w_i'} \tag{5}$$

where w_i' is a component of the eigenvector, and w_i is the normalized weight.

(4) *Consistency Verification*: This step ensures the rationality of the judgment matrix. Calculate the Consistency Index (CI) and Consistency Ratio (CR),

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{6}$$

$$CR = \frac{CI}{RI} \tag{7}$$

where RI is the Random Consistency Index (Table 3), dependent on the number of criteria n, A judgment matrix is considered consistent if $CR < 0.1$; otherwise, it requires adjustment.

Table 2. Pairwise Comparisons 1 to 9 Scale

Scale	Meaning
1	Two criteria are equally important
3	One criterion is slightly more important than the other
5	One criterion is obviously more important than the other
7	One criterion is much more important than the other
9	One criterion is absolutely more important than the other
2, 4, 6, 8	Intermediate values between the above scales

Table 3. Random Consistency Index (*RI*)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49

VIKOR Method

The VIKOR method has been systematically reviewed in sustainable and green decision-making (Mardani *et al.* 2016). Proposed by Opricovic, it is a typical MCDM tool for compromise ranking among conflicting indicators, particularly suitable for complex design scenarios where optimal solutions cannot be achieved through single indicators. Its core principle is to identify the most compromised solution that maximizes proximity to the ideal comprehensive optimal solution. Thus, VIKOR is ideal for design decision-making involving multi-stakeholder interests, conflicting indicators, and integration of subjective weights. This study applies VIKOR to the comprehensive evaluation and ranking of sustainable toy design schemes, with steps as follows:

(1) *Determine Evaluation Matrix and Ideal Solutions*: Construct a scheme-indicator evaluation matrix using AHP-derived weights and performance scores of three schemes across indicators:

$$X = [x_{ij}]_{m \times n} \tag{8}$$

where m is the number of schemes,n is the number of evaluation indicators, and x_{ij} is the quantitative score of scheme i on indicator j. Determine positive ideal solutions (f_j^*) and negative ideal solutions (f_j^-) based on indicator attributes:

$$f_j^* =* max(x_{ij}), f_j^- =* min(x_{ij}) \tag{9}$$

These ideal solutions serve as benchmarks for evaluating scheme performance.

(2) *Calculate Deviation from Ideal Solutions*: Measure the relative deviation of each scheme's performance from the ideal solution for individual indicator:

$$d_{ij} = \frac{f_j^* - x_{ij}}{f_j^* - f_j^-} \tag{10}$$

A smaller d_{ij} indicates closer proximity to the positive ideal value;$d_{ij} = 0$ denotes the ideal solution, and; $d_{ij} = 1$ indicates the worst performance.

(3) *Calculate Comprehensive Utility Value* (S_i) *and Maximum Regret Value (*R_i):

a) Comprehensive Utility Value (S_i): Reflects the overall deviation of the scheme across all indicators:

$$S_i = \sum_{j=1}^{n} w_j d_{ij} \tag{11}$$

where w_j is the AHP-derived indicator weight. A smaller S_i indicates better overall performance.

b) Maximum Regret Value (R_i): Reflects the deviation of the scheme's weakest-performing indicator:

$$R_i =* max_j\left(w_j d_{ij}\right) \tag{12}$$

Poor performance in a single indicator significantly increases the regret value.

(4) *Calculate Comprehensive Evaluation Index* (Q_i): Synthesizes S_i and R_i, in a compromise manner:

$$Q_i = v\frac{S_i - S^*}{S^- - S^*} + (1 - v)\frac{R_i - R^*}{R^- - R^*} \tag{13}$$

where $S^*$is the min (S_i), $S^-$is the max (S_i), $R^*$is the min (R_i), $R^-$is the max (R_i), and v is the weight of "group utility" (set to 0.5 in this study to balance group interests and worst-case performance). A smaller Q_i indicates closer proximity to the compromise optimal solution.

(5) D*etermine Optimal Scheme*: VIKOR makes decisions based on three rankings: ascending Q_i (compromise ranking, core), S_i (overall utility ranking), and R_i (weakest indicator ranking). The optimal scheme must satisfy two conditions:

Condition 1 (Acceptable Advantage):

$$Q(a') - Q(a) \geq \frac{1}{m - 1} \tag{14}$$

Condition 2 (Acceptable Stability): The scheme must rank first in either the S or R ranking. If both conditions are met, the scheme is the unique compromise optimal solution; otherwise, a candidate set of alternative solutions is formed.

CASE STUDY

Questionnaire Survey and Data Processing

To ensure a comprehensive understanding of user requirements, this study employed a combined approach of field research (observing children's interactions with wooden toys in kindergarten settings), semi-structured interviews, and questionnaire surveys to identify valid initial demand items. A total of 132 questionnaires were distributed, yielding 124 valid responses from three representative groups: parents (81), kindergarten teachers (25), and toy designers (18).

Table 4. Classification of Initial User Needs

Category	No.	Content
Safety Requirements	N1	Use safe, non-toxic, and degradable materials
	N2	Smooth edges and safe surface without harming hands
	N3	Sturdy structure, not easy to break
	N4	Safe size to prevent accidental swallowing and pinching
	N5	No irritating odor, safe coating
Educational and Gameplay Function Requirements	N6	Basic cognitive education function
	N7	Modular combination, pluggable and expandable
	N8	Adjustable difficulty with age
	N16	With digital interaction function
	N17	Provide very complex mechanism structure
Operational Convenience and Maintenance Requirements	N9	Easy to clean, not easy to absorb dust
	N10	Anti-loss of parts and provision of storage methods
	N11	Repairable with replacement parts provided
Parent-child Interaction and Emotional Experience Requirements	N12	Gameplay supporting parent-child interaction
	N13	Provide role stories (emotional companionship)
Sustainable Design and Aesthetic Style Requirements	N14	Traceable material sources
	N15	Multi-stage function transformation
	N18	Use excessively bright and high-saturation paint to cover wood texture

It is important to acknowledge that children, as the end-users, have limited cognitive capacity to articulate complex design preferences regarding sustainability. Therefore, this study focused on the 'Purchaser and Gatekeeper' perspective. Parents and teachers serve as valid proxies to evaluate the functional and ethical attributes (*e.g.*, non-toxic materials, educational value) that determine the actual purchase decision. While this approach may underrepresent the 'playfulness' perceived directly by children, it accurately reflects the market requirements for sustainable children's products. This tripartite structure ensures the research integrates usage scenarios, educational value, and manufacturing viability, comprehensively reflecting needs across five dimensions (Table 4).

Based on field observations and interview results, a KANO model two-factor questionnaire (Table 5) with positive and negative questions was designed to expand the initial user needs list (Table 4). The questionnaire included 18 initial demand items, covering safety, educational development, functionality, operational convenience, maintenance, emotional experience, parent-child interaction, and sustainability, and classified needs into M, O, A, I, and R types using the KANO model. Respondents rated the importance of each demand on a 5-point Likert scale for both positive (presence of the feature) and negative (absence of the feature) questions: Strongly Like (5), Must-have (4), Neutral (3), Tolerable (2), and Strongly Dislike (1).

Table 5. KANO Model Two-Factor Questionnaire

Attitude when the function is available (Positive)					User Needs for Sustainable Wooden Toys	Attitude when the function is not available (Negative)				
5	4	3	2	1		1	2	3	4	5
					N1 Use safe, non-toxic, degradable materials					
					N2 Smooth edges, safe surface without harming hands					
					N3 Sturdy structure, not easy to break					
					N4 Safe size to prevent accidental swallowing and pinching					
					N5 No irritating odor, safe coating					
					N6 Basic cognitive education function					
					N7 Modular combination, pluggable and expandable					
					N8 Adjustable difficulty with age					
					N9 Easy to clean, not easy to absorb dust					
					N10 Anti-loss of parts and provision of storage methods					
					N11 Repairable with replacement parts provided					
					N12 Gameplay supporting parent-child interaction					
					N13 Provide role stories					
					N14 Traceable material sources					
					N15 Multi-stage function transformation					
					N16 With digital interaction function					
					N17 Provide very complex mechanism structure					
					N18 Use excessively bright and high-saturation paint to cover wood texture					

To ensure the quality of the survey data prior to classification, reliability analysis was conducted on the 5-point Likert scale responses for both functional (positive) and dysfunctional (negative) questions. The Cronbach's α coefficients for positive and negative items were 0.948 and 0.944, respectively, exceeding the 0.8 threshold. This indicates that the respondents maintained high internal consistency in their rating logic, minimizing the risk of random or careless responses. Furthermore, the KMO and Bartlett's sphericity tests were performed to assess the structural suitability of the data: KMO values were 0.952 (positive) and 0.946 (negative); Bartlett's sphericity test yielded $\chi^2 = 1493.053$ (df = 153, $p < 0.001$) and 1399.730 (df = 153, $p < 0.001$). While these metrics do not directly validate the specific Kano categories, they confirm the statistical robustness of the underlying dataset, providing a solid foundation for the subsequent demand classification and weight calculation.

Using the Kano classification matrix and coefficient formulas, 18 initial user needs were categorized (Table 6). Among them, 5 were classified as Must-be (M), 6 as One-dimensional (O), 4 as Attractive (A), 2 as Indifferent (I), and 1 as Reverse (R).

Table 6. KANO Questionnaire Analysis Results for Wooden Children's Toys

User Needs	A	O	M	I	R	Q	Classification Result	Better	Worse
N1	16.94%	8.06%	45.97%	17.74%	7.26%	4.03%	M	28.18%	-60.91%
N2	15.32%	7.26%	50.81%	15.32%	8.87%	2.42%	M	25.45%	-65.45%
N3	21.77%	4.03%	62.10%	6.45%	3.23%	2.42%	M	27.35%	-70.09%
N4	18.55%	5.65%	48.39%	16.13%	6.45%	4.84%	M	27.27%	-60.91%
N5	25.00%	6.45%	41.94%	12.90%	10.48%	3.23%	M	36.45%	-56.07%
N6	20.97%	44.35%	15.32%	4.84%	9.68%	4.84%	O	76.42%	-69.81%
N7	19.35%	46.77%	11.29%	9.68%	5.65%	7.26%	O	75.93%	-66.67%
N8	17.74%	45.97%	11.29%	11.29%	5.65%	8.06%	O	73.83%	-66.36%
N9	14.52%	48.39%	10.48%	9.68%	9.68%	7.26%	O	75.73%	-70.87%
N10	13.71%	44.35%	14.52%	12.90%	6.45%	8.06%	O	67.92%	-68.87%
N11	12.90%	46.77%	12.10%	12.90%	5.65%	9.68%	O	70.48%	-69.52%
N12	51.61%	5.65%	17.74%	13.71%	6.45%	4.84%	A	64.55%	-26.36%
N13	45.16%	7.26%	16.13%	20.97%	10.48%	0.00%	A	58.56%	-26.13%
N14	48.39%	10.48%	17.74%	12.90%	10.48%	0.00%	A	65.77%	-31.53%
N15	43.55%	4.84%	18.55%	19.35%	7.26%	6.45%	A	56.07%	-27.10%
N16	20.97%	7.26%	14.52%	41.13%	12.90%	3.23%	I	33.65%	-25.96%
N17	16.94%	9.68%	10.48%	49.19%	9.68%	4.03%	I	30.84%	-23.36%
N18	1.61%	8.06%	17.74%	20.16%	50.81%	1.61%	R	20.34%	-54.24%

Must-be Attributes (M): N1 (safe, non-toxic, degradable materials), N2 (smooth edges), N3 (sturdy structure), N4 (safe size), and N5 (non-irritating odor/coatings). Users consider these essential; their presence does not significantly improve satisfaction, but their absence drastically reduces it—these must be addressed in design.

One-dimensional Attributes (O): N6 (basic cognitive functions), N7 (modular assembly), N8 (age-adjustable difficulty), N9 (easy to clean), N10 (anti-loss + storage), and N11 (repairable with replacement parts). These are critical for satisfaction, their presence increases satisfaction, while absence decreases it—priority should be given to these in design.

Attractive Attributes (A): N12 (parent-child interaction), N13 (role-play stories), N14 (traceable materials), and N15 (multi-stage transformation). These exceed user expectations, delivering delight, their presence significantly boosts satisfaction, while absence has minimal impact—efforts should be made to incorporate these.

Indifferent Attributes (I): N16 (digital interaction) and N17 (complex mechanisms). Users are indifferent to these; they do not affect satisfaction and are not design priorities.

Reverse Attribute (R): N18 (overly bright paint covering wood grain). This reduces satisfaction when present and should be excluded from design.

Weight Analysis of User Needs

Based on the KANO model's qualitative screening, Indifferent (N16, N17) and Reverse (N18) attributes—with insignificant or negative impacts on user satisfaction—were excluded, leaving 15 key user demand indicators. To eliminate subjective ambiguity in design decisions, AHP was introduced to construct an evaluation model, converting qualitative user needs into quantitative weights to establish a priority system for design elements. As shown in Fig. 3, the 15 screened indicators were organized into a hierarchical structure: 1 target layer (A: Sustainable Wooden Toy Design Evaluation System), 4 criterion layers (B1: Safety Requirements; B2: Educational & Interactive Functions; B3: Structure & Usability; B4: Ecological & Sustainability), and 15 indicator layers.

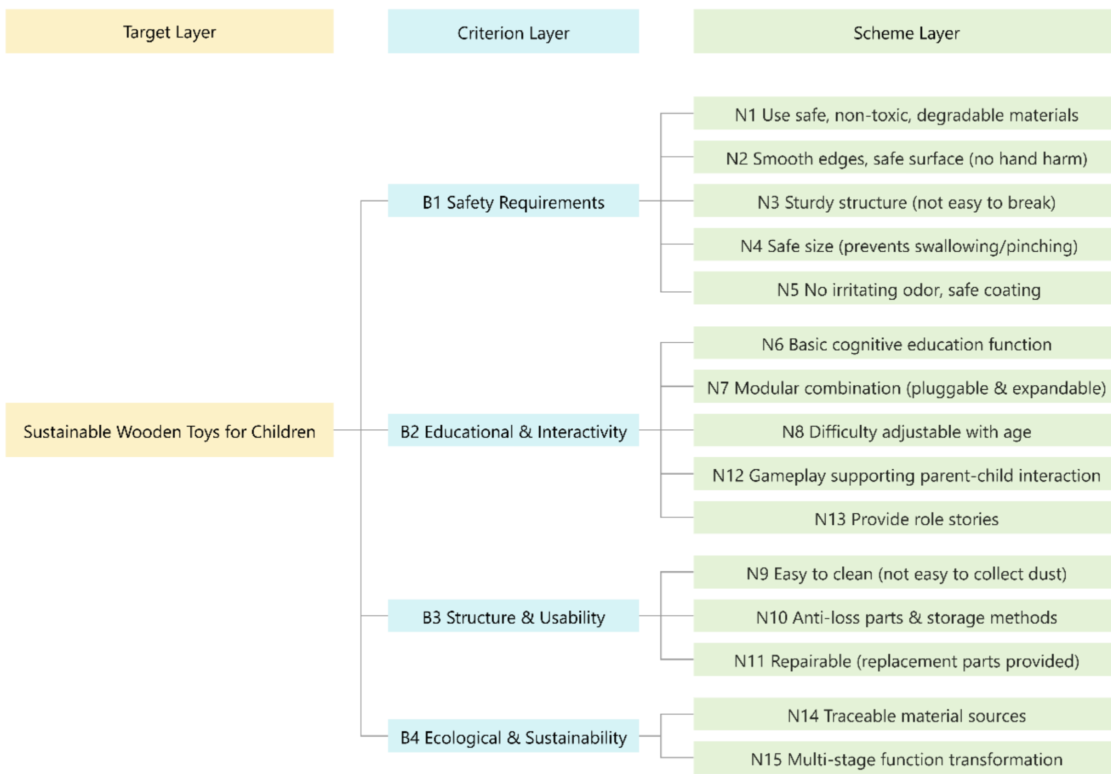

Fig. 3. Sustainable wooden toy design evaluation system

To ensure the rigor and professionalism of weight indicators, an expert panel of 18 professionals was convened, including 4 university product design faculty, 5 senior toy designers, 4 highly informed parents, and 3 experts in sustainable materials and design—all with over 5 years of experience in their respective fields. The panel used Saaty's 1 to 9 scale (Table 2) for pairwise comparisons of indicators at each level. To mitigate extreme opinions, geometric mean aggregation was applied to the panel's ratings to construct the final group judgment matrix.

Reflecting the strict regulatory standards of the children's product industry (*e.g.*, EN71, ASTM F963), the expert panel explicitly established 'Safety' as the foundational constraint. Consequently, in the pairwise comparison, Safety (B1) was prioritized over Ecological Sustainability (B4) and Educational Interaction (B2). This hierarchy represents a necessary ethical and legal premise for toy design, rather than a purely data-driven discovery. Based on this consensus, the criterion layer judgment matrix (A) and weight results were derived (Table 7).

Table 7. Criterion Layer Judgment Matrix and Weight Results

Target A	B1	B2	B3	B4	Weight Vector w_i
B1	1	3	5	2	0.482
B2	1/3	1	2	1/2	0.157
B3	1/5	1/2	1	1/3	0.088
B4	1/2	2	3	1	0.273

Consistency verification was performed to ensure data reliability (Table 8). The maximum eigenvalue λ_{max}= 4.015, CI = 0.005, and CR = 0.0056 < 0.1, indicated high consistency of the criterion layer judgment matrix. The weight order (B1 > B4 > B2 > B3) meets consistency standards.

Table 8. Consistency Verification Results

Maximum Eigenvalue λ_{max}	CI Value	RI Value	CR Value	Consistency Test Result
4.015	0.005	0.890	0.0056	Passed

Subsequently, judgment matrices were constructed for sub-indicators under each criterion using the 1 to 9 scale to ensure clear hierarchical comparisons. As shown in Tables 9 to 12, CR values (0.016, 0.015, 0.009, and 0.000) are all < 0.1, confirming consistency of the indicator layer judgment matrices.

Table 9. Judgment Matrix for Safety & Materials (B1)

B1	N1	N2	N3	N4	N5	Weight
N1	1	3	3	2	5	0.410
N2	1/3	1	1	1/2	2	0.135
N3	1/3	1	1	1/2	2	0.135
N4	1/2	2	2	1	3	0.241
N5	1/5	1/2	1/2	1/3	1	0.074
(CR = 0.004 < 0.1, Consistency passed)						

Table 10. Judgment Matrix for Educational & Interactive Functions (B2)

B2	N6	N7	N8	N12	N13	Weight
N6	1	1/3	2	1/2	3	0.160
N7	3	1	4	2	5	0.417
N8	1/2	1/4	1	1/3	2	0.097
N12	2	1/2	3	1	4	0.263
N13	1/3	1/5	1/2	1/4	1	0.062
(CR = 0.015 < 0.1, Consistency passed)						

Table 11. Judgment Matrix for Structure & Usability (B3)

B3	N9	N10	N11	Weight
N9	1	1/2	1/3	0.163
N10	2	1	1/2	0.297
N11	3	2	1	0.540
(CR = 0.009 < 0.1, Consistency passed)				

Table 12. Judgment Matrix for Ecological & Sustainability (B4)

B4	N14	N15	Weight
N14	1	3	0.750
N15	1/3	1	0.250
(CR = 0.000 < 0.1, Two-order matrix is completely consistent)			

The relative weight results (Table 13) align with Kano model demand classifications, indicating that in sustainable wooden toy design, in addition to meeting Must-be requirements, high-ranked One-dimensional (O) needs (*e.g.*, “modular assembly, interlocking/expandable”(N7) and “repairable with replacement parts”(N11)) and Attractive (A) needs (*e.g.*, “traceable material sources”(N14) and “multi-stage functional transformation”(N15)) must be prioritized. This breaks the limitations of traditional toys focusing solely on basic functions, achieving dual improvements in user experience and environmental benefits.

Table 13. Ranking of Global Relative Weights

Rank	User Needs	AHP Criterion Layer	KANO Classification	AHP Global Relative Weight
1	N14	B4	A	0.205
2	N1	B1	M	0.198
3	N4	B1	M	0.116
4	N15	B4	A	0.068
5	N7	B2	O	0.066
6	N2	B1	M	0.065
7	N3	B1	M	0.065
8	N11	B3	O	0.048
9	N12	B2	A	0.041
10	N5	B1	M	0.036
11	N10	B3	O	0.026
12	N6	B2	O	0.025
13	N8	B2	O	0.015
14	N9	B3	O	0.014
15	N13	B2	A	0.010

Overall, Kano classification and AHP weight distribution are consistent: Must-be attributes focus on safety and health, Attractive attributes emphasize ecological sustainability, and One-dimensional attributes relate to functional improvement and user experience enhancement—providing weight basis and design priorities for subsequent VIKOR-based scheme selection.

Design Schemes

Based on Kano classification and AHP global relative weight rankings, five design schemes with distinct focuses were developed (Figs. 4 and 5). These schemes strictly adhere to safety (B1) as the primary Must-be attribute while exploring educational interaction (B2), operational convenience/maintenance (B3), and parent-child interaction/emotional experience (B4) throughout the product lifecycle. The design process prioritizes high-weight indicators, such as "traceable material sources (N14)" and "safe, non-toxic materials (N1)," aiming to achieve dynamic balance among functionality, education, and ecology.

- **Scheme 1**: This scheme features a pure wooden scroll linkage structure for dynamic visual storytelling, with a sturdy design and safe size to prevent swallowing/ pinching. The scheme emphasizes parent-child interactive gameplay, allowing parents and children to engage in joint story reading (meeting Attractive attributes to enhance user stickiness). The base includes various mold shapes, transforming children's motor experiences into narrative progression and endowing wooden materials with profound emotional companionship value.
- **Scheme 2**: This scheme retains natural wood textures without excessive coating, thereby preserving the inherent colors of different tree species and avoiding high-saturation paints. It delivers sustainable values through tactile perception. In addition, it offers diverse building blocks simulating forest ecosystems, providing a role-play narrative carrier for parent-child interaction and enhancing the educational quality of family companionship. Incorporates traceability nodes to strengthen emotional trust in materials, enabling children to develop initial ecological awareness through simulated forest construction (meeting Attractive needs). The scheme focuses on ecological aesthetic communication and natural cognitive education, emphasizing children's intuitive perception of material origins and natural textures.
- **Scheme 3**: This scheme adopts high-safety sanding technology, with all main components meeting non-toxic, odorless Must-be attribute standards to ensure absolute safety during outdoor interaction. It integrates modular toy concepts, transforming into a spinning top or a combination of spinning top and wooden stick. The spinning top features open physical slots, encouraging children to collect outdoor leaves and feathers as components, creating a direct connection between toy form and the natural environment.
- **Scheme 4**: Main components undergo multi-stage precision sanding to ensure structural sturdiness and absence of irritating odors (meeting safety as the primary principle). The scheme combines construction logic with vocal enlightenment, guiding children to build composite tracks with sound tubes and slides to intuitively understand gravity, balance, and tonal variations. The interlocking logic allows difficulty adjustment based on children's cognitive levels, precisely meeting the One-dimensional need for "age-adjustable difficulty" with high innovation. The scheme focuses on educational value as the core breakthrough, exploring the interdisciplinary integration of physical mechanics construction and musical enlightenment.
- **Scheme 5**: This scheme uses FSC-certified sustainable solid wood as the core material, ensuring traceable and naturally degradable materials. As the most integrated design prototype, it is positioned as a transformable wooden furniture system integrating learning, gaming, storage, and mobility, deeply addressing operational convenience/maintenance needs and the One-dimensional attribute of long service life. The core design lies in "modular assembly" and "free form transformation." Through

precision wooden adjustment structures, the product flexibly switches between "learning desk-chair mode" and "fun game slide-drawing board mode." The base is equipped with anti-slip wooden wheels for easy movement across different home functional areas.

Fig. 4. Design schemes 1 to 4

Fig. 5. Design scheme 5

Determination of the Optimal Scheme

To identify the optimal compromise scheme that balances user demand weights and multi-criteria constraints, an interdisciplinary expert team of 40 professionals was assembled for multi-attribute evaluation, including 9 toy designers, 11 parents, 8 university product design faculty, and 12 sustainability experts.

Table 14. Initial Evaluation Score Matrix

KANO Attribute	User Need Evaluation Indicators	Global Relative Weight	Scheme 1	Scheme 2	Scheme 3	Scheme 4	Scheme 5	Indicator Type
M (Must-be)	N1 Safe and non-toxic materials	0.198	8.5	9.0	8.8	8.7	9.2	Benefit-type
	N4 Size preventing accidental swallowing/pinching	0.116	8.2	8.5	8.4	8.3	9.0	Benefit-type
	N2 Smooth edges without harming hands	0.065	8.8	8.6	9.0	8.5	8.9	Benefit-type
	N3 Sturdy structure not easy to break	0.065	8.0	7.8	8.2	8.4	9.1	Benefit-type
	N5 Safe coating without odor	0.036	8.5	9.2	8.5	8.6	9.0	Benefit-type
O (One-dimensional)	N7 Modular plug-in expansion	0.066	6.5	8.0	7.5	8.2	9.5	Benefit-type
	N11 Repairable/replaceable parts	0.048	6.0	7.2	7.0	6.8	9.2	Benefit-type
	N10 Anti-loss storage of parts	0.026	7.2	7.5	6.5	7.0	9.4	Benefit-type
	N6 Basic cognitive education	0.025	8.5	8.2	7.8	9.0	8.8	Benefit-type
	N8 Age-adjustable difficulty	0.015	6.2	7.0	7.5	8.8	9.3	Benefit-type
	N9 Easy to clean and not easy to absorb dust	0.014	7.5	8.8	7.8	7.2	7.8	Benefit-type
A (Attractive)	N14 Traceable material sources	0.205	7.8	8.8	8.0	7.5	9.6	Benefit-type
	N15 Multi-stage function transformation	0.068	6.5	7.0	6.8	7.2	9.7	Benefit-type
	N12 Parent-child interactive gameplay	0.041	8.4	8.6	7.8	8.2	9.0	Benefit-type
	N13 Provision of role stories	0.010	9.2	8.5	6.5	7.2	7.5	Benefit-type

Expert selection followed the same principles as the AHP weight determination stage, with expanded size and composition to ensure comprehensive evaluation perspectives.

Prior to formal evaluation, a rigorous “scoring anchor” protocol was established to minimize subjective variance. Experts were briefed on the definitions of 15 key indicators

To ensure consistency, explicit scoring anchors were established. For example, regarding 'Traceability (N14),' a score of 9 to 10 was strictly defined as 'Certified Sustainable Origin (*e.g.*, FSC),' while a score of 1 to 2 indicated 'Unknown material origin.' The experts then rated each scheme's performance independently. To mitigate the impact of extreme outliers, the geometric mean was employed to aggregate the scores into the initial evaluation matrix (Table 14). Combined with AHP-derived global relative weights, this matrix provided a scientific basis for subsequent VIKOR multi-attribute optimization ranking, ensuring evaluation objectivity, comparability, and result interpretability.

Using the initial evaluation matrix, the VIKOR method was applied for multi-attribute optimization analysis of the five schemes. With the group utility weight v = 0.5, the comprehensive utility value (S_i), maximum regret value (R_i), and comprehensive evaluation index (Q_i) were calculated using Eqs. 11 to 13 (Table 15).

Table 15. VIKOR Analysis Results

Scheme	Comprehensive Utility Value S_i	Maximum Regret Value R_i	Comprehensive Evaluation Index Q_i	Rank
Scheme 1	0.8675	0.1984	0.9818	5
Scheme 2	0.5066	0.0783	0.4508	2
Scheme 3	0.6968	0.1565	0.7695	3
Scheme 4	0.7707	0.2054	0.9414	4
Scheme 5	0.0426	0.0130	0.0000	1

VIKOR finalizes decisions based on ascending rankings of Q_i, R_i, and S_i. Table 15 shows the ranking order: Scheme 5 > Scheme 2 > Scheme 3 > Scheme 4 > Scheme 1. The optimal scheme must meet both acceptable advantage and decision stability constraints:

Condition 1: $Q(a2) - Q(a1)$ = 0.4508−0.000 = 0.4508 ≥ 0.25 (satisfied).

Condition 2: Scheme 5 ranks first in both S and R rankings (satisfied).

Thus, Scheme 5 was identified as the unique compromise optimal solution.

DISCUSSION

Interpretation of the "Compromise" Solution

The selection of Scheme 5 (Modular Furniture-Toy) as the optimal compromise solution is a logical consequence of the "Safety-First, Ecology-Second" weight hierarchy established by the AHP analysis. While Scheme 4 demonstrated superior performance in "educational interaction" (B2), the VIKOR method penalized it for weaker performance in the highest-weighted categories. In contrast, Scheme 5 achieved the highest scores in "Traceability" (N14, Weight 0.205) and "Safety" (N1, Weight 0.198). This result confirms that the Kano-AHP-VIKOR framework functions effectively as a "gatekeeper," strictly filtering out designs that prioritize "fun" (Educational/Interactive) at the expense of the stakeholder's core requirements for safety and sustainability. The "compromise" here represents a mathematically robust balance, where the "regret" of sacrificing some educational complexity is minimized to ensure compliance with critical environmental and safety standards.

Addressing Bias and Sample Limitations

A critical limitation of this study is the reliance on adults (parents, teachers, and designers) to articulate the needs of children. While this approach mitigates the cognitive difficulties young children face in expressing complex preferences, it inevitably introduces an "adult-centric" bias. The "User Needs" identified in this study (*e.g.*, durability, traceability) essentially reflect the "Purchaser's Criteria" rather than the "User's Play Experience." Consequently, the resulting design priorities emphasize the "Gatekeeper" factors (safety and ecology) that influence the purchase decision. Future research should incorporate direct observational data of children interacting with prototypes to verify whether the "Attractive" attributes identified by adults (such as modular transformation) genuinely sustain children's engagement over time, thereby balancing the "purchaser's logic" with the "user's reality".

Validation Scope and Implications for Design

It is important to clarify the scope of "verification" in this research. Unlike engineering studies that employ Life Cycle Assessment (LCA) to quantify physical environmental impacts (*e.g.*, carbon footprint), this study validates the consistency between stakeholder requirements and design outcomes. The success of Scheme 5 validates that the proposed framework can successfully translate abstract sustainable concepts—specifically "Traceability" (N14) and "Multi-stage Transformation" (N15)—into tangible product features that are preferred by the target market. From a design perspective, the study suggests that extending product lifecycle through functional transformation (*e.g.*, converting furniture to toys) is perceived by stakeholders as a more effective sustainable strategy than material substitution alone. This provides a clear directive for designers: to increase the "green value" of wooden toys, priority should be placed on verifying the supply chain (FSC certification) and designing for longevity through modularity.

CONCLUSIONS

1. This study systematically identified and classified user needs for wooden children's toys using the Kano model. From the perspective of key stakeholders (parents and teachers), safety was confirmed as the fundamental "Must-be" attribute, while material traceability and functional diversity were identified as core "Attractive" drivers. Building on this, a rigorous weight system was established via AHP, where "traceable material sources (N14)" (weight = 0.205) and "safe non-toxic materials (N1)" (weight = 0.198) ranked highest. This quantitative distribution revealed a clear "Safety-First, Ecology-Oriented" preference structure, providing a scientific basis for prioritizing conflicting design objectives.
2. In the scheme selection phase, multi-attribute optimization *via* the VIKOR method identified Scheme 5 as the optimal compromise solution due to its outstanding performance across high-weight core indicators. With a comprehensive index Q_i= 0.000, Scheme 5 outperformed all alternatives specifically due to its strict alignment with the top-weighted indicators (Traceability and Safety). By integrating "modular assembly" with "furniture-toy transformation," Scheme 5 demonstrated that extending product lifecycle is a preferred sustainable strategy over material

substitution alone, validating the framework's effectiveness in translating high-priority weights into tangible design features.

3. Ultimately, this research constructs a systematic design framework based on Kano-AHP-VIKOR, forming a logical closed loop from stakeholder demand identification to multi-objective scheme ranking. Rather than merely labeling products as "green," this integrated system offers a quantifiable method to manage the trade-offs between educational value and environmental constraints. It provides an operable decision-making pathway for the sustainable design of wooden toys and serves as a theoretical reference for developing other products where purchaser priorities (safety/ sustainability) must balance with user experience.

ACKNOWLEDGEMENTS

The authors sincerely acknowledge all participants and experts for their valuable contributions to this research. This study was supported by the following projects: the 2024 Key Second Round Assignment Project of Guangdong Rural Science and Technology Commissioners for the "Hundred-Thousand-Ten Thousand Project" initiated by the Department of Science and Technology of Guangdong Province, entitled "Brand Building, Promotion and Marketing of Pantian Rice Noodles as Agricultural Products" (Project No.: KTP20240308); and the 2025 Guangdong Provincial Education Science Planning Project (Higher Education Special Topic) titled "Research on the Training Model of Applied Agriculture-Related Design Innovative Talents Driven by University-Local Symbiosis under the Rural Revitalization Strategy" (Project No.: 2025GXJK0395).

To ensure research integrity and transparency, the authors declare that ChatGPT 5.1 (OpenAI) was used exclusively for English translation and language refinement. All aspects of research design, data analysis, and the formulation of conclusions were independently conducted by the authors.

REFERENCES CITED

Brioso, X., and Calderon-Hernandez, C. (2023). "Framework for integrating productive, contributory, and noncontributory work with safe and unsafe acts and conditions," *International Journal of Environmental Research and Public Health* 20(4), article 3412. http://doi.org/10.3390/ijerph20043412

Cao, X., Hsu, Y., and Wu, W. (2021). "Cross-cultural design: A set of design heuristics for concept generation of sustainable packagings," in: *Cross-Cultural Design. Experience and Product Design Across Cultures*, Springer, Cham, Switzerland, pp. 197-209. https://doi.org/10.1007/978-3-030-77074-7_16

Chen, Y., Shamsudin, R., Tawakkal, I., Me, R., and Basri, M. (2025). "Analyzing product design system application children's toys based on sustainable materials and processes," *Entertainment Computing* 54, article 100947. http://doi.org/10.1016/j.entcom.2025.100947

Ferreira, A., Noronha, E., Sousa, R., and Serra, G. (2024). "A sustainable cork toy that promotes the development of blind and visually impaired young children," *Sustainability* 16(15), article 6312. http://doi.org/10.3390/su16156312

Kovačič Lukman, R., Omahne, V., and Krajnc, D. (2021). "Sustainability assessment with integrated circular economy principles: A toy case study," *Sustainability* 13(7), article 3856. http://doi.org/10.3390/su13073856

Levesque, S., Robertson, M., and Klimas, C. (2022). "A life cycle assessment of the environmental impact of children's toys," *Sustainable Production and Consumption* 31, 777-793. http://doi.org/10.1016/j.spc.2022.03.001

Li, Y., and Xue, L. (2023). "Children's toy design process based on the Kano-AHP-FBS model: Case of multisensory educational toys," in: *2023 International Conference on Culture-Oriented Science and Technology (CoST)*, Xi'an, China, pp. 311-316. http://doi.org/10.1109/CoST60524.2023.00070

Mardani, A., Zavadskas, E. K., Govindan, K., Amat Senin, A., and Jusoh, A. (2016). "VIKOR technique: A systematic review of the state of the art literature on methodologies and applications," *Sustainability* 8(1), article 37. http://doi.org/10.3390/su8010037

Miao, Y., Xie, X., Qi, W., and Xu, W. (2024). "Design of kindergarten toy lockers," *BioResources* 19(1), 434-455. http://doi.org/10.15376/biores.19.1.434-455

Miao, Y., Xie, X., Wang, H., and Xu, W. (2025). "A study on the design of literacy toy for children with parent-child interactions," *Scientific Reports* 15(1), article 6793. http://doi.org/10.1038/s41598-025-91077-x

Mikulic, J., and Prebezac, D. (2011). "A critical review of techniques for classifying quality attributes in the Kano model," *Managing Service Quality* 21(1), 46-66. http://doi.org/10.1108/09604521111100243

Saaty, R. (1987). "The analytic hierarchy process—what it is and how it is used," *Mathematical Modelling* 9(3), 161-176. http://doi.org/https://doi.org/10.1016/0270-0255(87)90473-8

Takato, K., and Shirayama, S. (2012). "An engineering education toward sustainable society through manufacturing a flying toy Taketombo," *Journal of Advanced Mechanical Design Systems and Manufacturing* 6(7), 1143-1153. http://doi.org/10.1299/jamdsm.6.1143

Tu, J., Chu, K., Gao, D., and Yang, C. (2022). "Analyzing decision-making factors of green design for kid's toys based on the concept of product lifecycle," *Processes* 10(8), article 1523. http://doi.org/10.3390/pr10081523

Wang, X., Yang, T., Zhang, Y., and Xu, S. (2023). "The application of Kano model in the design of children's interactive educational products," in: *HCI International 2023 – Late Breaking Papers*, Springer, Cham, Switzerland, pp. 308-319. https://doi.org/10.1007/978-3-031-48060-7_23

Watkins, M., Casamayor, J., Ramirez, M., Moreno, M., Faludi, J., and Pigosso, D. (2021). "Sustainable product design education: Current practice," *She Ji-The Journal of Design Economics and Innovation* 7(4), 611-637. http://doi.org/10.1016/j.sheji.2021.11.003

Xu, C., Yu, H., Zhang, S., Shen, C., Ma, C., Wang, J., and Li, F. (2024). "Cleaner production evaluation system for textile industry: An empirical study," *The Science of the Total Environment* 913, article 169632. http://doi.org/10.1016/j.scitotenv.2023.169632

Yamane, Y., and Kayo, C. (2025). "Environmental impact assessment of toys toward sustainable toy production and consumption in Japan," *Sustainability* 17(6), article 2351. http://doi.org/10.3390/su17062351

Article submitted: January 6, 2026; Peer review completed: February 7, 2026; Revised version received: February 12, 2026; Published: February 25, 2026.
DOI: 10.15376/biores.21.2.3469-3491