A User-Centered Sustainable Design Research for Parent-Child Interactive Seating in Urban Children's Parks: Development of an Integrated GT-KANO-AHP-QFD Model

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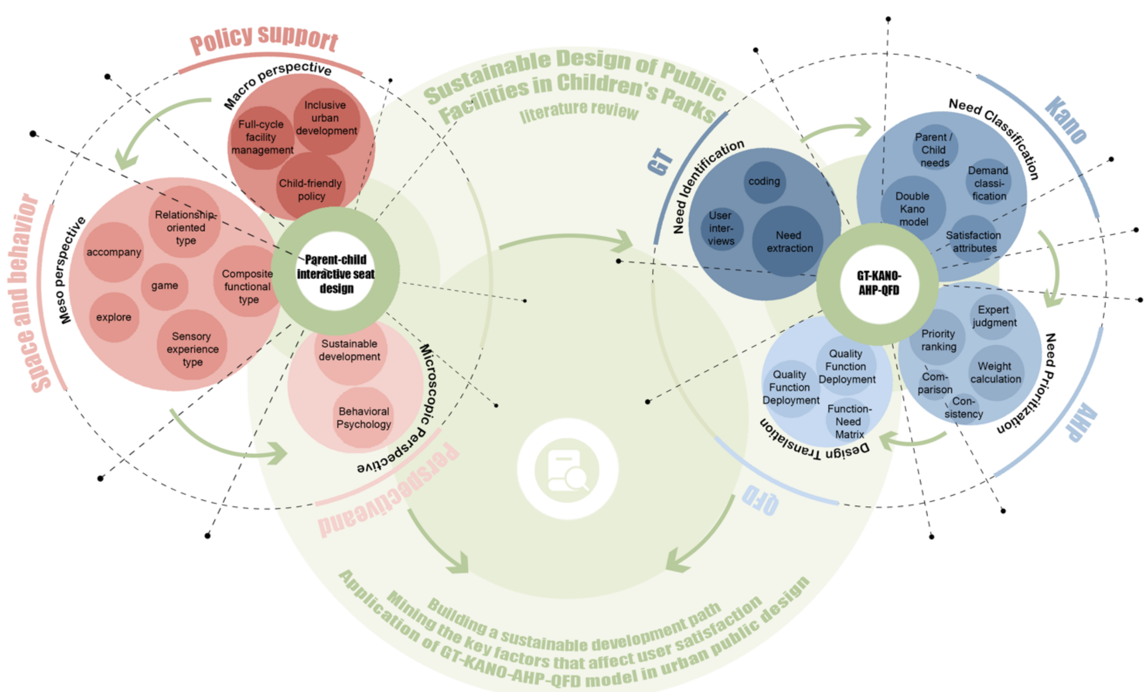
GRAPHICAL ABSTRACT



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Urban parks have increasingly become pivotal settings for strengthening parent–child relationships; however, most on-site facilities remain predominantly adult-oriented. Accordingly, this study developed an operational, replicable, and iterative research framework for parent–child interactive seating in children's parks, placing parent–child needs and sustainable design at its core. Anchored in the Double-Diamond process, a GT–Kano–AHP–QFD integrated innovation model was proposed to extract, classify, weight, and translate user requirements for such seating. By integrating these four methods, user needs were captured and addressed more precisely, thereby deepening understanding of design requirements for parent–child interactive seating. A rapid ideation workflow was subsequently implemented, combining large language models with diffusion models to generate concepts. The scheme was evaluated with fuzzy comprehensive evaluation (FCE), which indicated that the embedded, multifunctional interaction concept achieved the highest performance in functional adaptability, emotional interactivity, and life-cycle sustainability (composite score = 0.840). The findings demonstrated that the integrated innovation model simultaneously enhances user satisfaction and reduces carbon impact, providing a transferable procedural paradigm and empirical evidence for the sustainable design of parent–child seating and other micro-scale public amenities.

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Keywords: User-Centered Design; Children's park; Parent-child interactive seats; Sustainable design; GT-KANO-AHP-QFD integrated innovation model

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INTRODUCTION

With the ongoing progression of urbanization, public spaces have become increasingly scarce, and the availability of open activity areas for children has been significantly reduced (Huang *et al.* 2024; Sen and Gredebäck 2024). As a result, urban parks have emerged as essential environments for facilitating parent-child communication and fostering both emotional bonding and overall well-being (Chen *et al.* 2024). Among these, children's parks function not only as sites for recreation and social interaction but also as critical venues for parent-child engagement (Chen *et al.* 2020). It has been demonstrated by Hsin that high-quality parent-child interactions in outdoor contexts significantly contribute to children's cognitive development (Hsin 2009). Moreover, it has been emphasized by Cameron-Faulkner *et al.* (2018) that park environments help alleviate negative emotions, foster creativity in children, and provide essential opportunities for parental education and companionship. Consequently, under the spatial constraints of urban settings, the optimization of public facility design to enhance parent-child interaction has become a critical concern in contemporary urban planning discourse. Meanwhile, children's parks, as highly flexible units within urban space, offer spatial advantages for accommodating novel and multifunctional facilities. Compared with standardized street spaces, they are more conducive to the integration of interactive and exploratory "non-routine objects" that attract repeated engagement from children and stimulate sustained interest. This, in turn, enhances the level of parent–child participation and increases the stickiness of public space usage.

Seating has been regarded as one of the most fundamental elements of public infrastructure in children's parks (Main and Hannah 2010). However, its design has traditionally been characterized by an adult-oriented bias, frequently overlooking the interactive needs of children and their parents (Yang *et al.* 2023; Lin *et al.* 2024), resulting in misaligned perceptions among users (Zhang *et al.* 2024). Consequently, consideration of parent-child interaction scenarios has been acknowledged as essential for improving the quality of shared experiences between children and caregivers (Cagiltay *et al.* 2023). At the same time, growing attention has been directed toward the carbon footprint of public infrastructure such as park seating, due to increasing global concerns over sustainability (Yang and Vezzoli 2024; Zhang and Sun 2024). A life cycle assessment (LCA) of 14 types of public benches in Turkey, as conducted by Sipahi and Sipahi (2024), indicated that most carbon emissions were concentrated during the phases of material extraction and end-of-life disposal. It has also been emphasized by Yang (2022) that design strategies play a decisive role in shaping environmental impacts throughout the product life cycle. When principles of the circular economy are incorporated into the design process, the carbon footprint of seating systems can be substantially minimized. In summary, within the context of children's parks, empirical research remains limited in concurrently addressing both the interactive needs of parent-child users and the implementation of sustainable design strategies. This study aimed to develop and validate an operational and replicable integrated process model to guide the identification of user needs and the sustainable design practice of parent–child interactive seating in children's parks.

The user-centered design paradigm has been increasingly regarded as a novel framework for addressing existing research gaps. Grounded Theory (GT), the Kano model, the Analytic Hierarchy Process (AHP), and Quality Function Deployment (QFD) have been widely acknowledged as fundamental methodological tools for identifying and translating user needs (Mao *et al.* 2005; Lyon and Koerner 2016). GT has been applied to extract both explicit and implicit user needs from complex social environments (Mulgund *et al.* 2021). The Kano model has been employed to illustrate the asymmetric influence of various user needs on user satisfaction (Xu *et al.* 2009). AHP has been used to construct a structured model for quantifying the relative weights of criteria in multi-criteria decision-making (Gompf *et al.* 2021), while QFD has been applied to transform prioritized user needs into actionable functional attributes (Prasad 1998). These methodologies have been adopted across a range of domains, and several studies have attempted to integrate selected methods within product design contexts (Wu and Liao 2021; Chen *et al.* 2022; Wang *et al.* 2025). However, in the context of sustainable design for parent-child interactive seating in children's parks, no empirical research to date has examined the integrated use of GT, Kano, AHP, and QFD methods.

In summary, an integrated innovation model grounded in GT, the Kano model, AHP, and QFD is proposed, with a central focus on user needs and sustainable design. The objective is to establish a research framework that is operational, replicable, and iterative, tailored to the design of parent-child interactive seating in children's parks. First, explicit and implicit user needs during shared usage scenarios were identified through GT, which was applied within real-world park environments. Second, the Kano model was applied to administer structured questionnaires to parents and children separately, facilitating the classification of user needs and the analysis of their asymmetric effects on satisfaction. Third, expert weighting was conducted using AHP to quantify the relative importance of each identified need. Fourth, sustainability indicators—such as life-cycle carbon emissions and circular material utilization—were integrated into the QFD House of Quality, enabling the bi-directional alignment between user satisfaction and sustainability objectives. Based on these steps, a design solution was developed that emphasizes emotional engagement, functional adaptability, and ecological sustainability. Finally, a fuzzy comprehensive evaluation was performed to assess the performance of the prototype under real-world application conditions. This study provides a replicable chain of evidence for embedding "user experience–environmental performance" across the full life cycle of public facilities in urban space design, thereby supporting child-friendly, low-carbon, and sustainable design and operation decisions.

Based on the identified research gaps and methodological framework, this study proposed the following hypotheses:

H1: If the functional and formal design of parent–child interactive seating simultaneously integrates the dual needs of children and their caregivers, it will significantly enhance users' interaction satisfaction.

H2: Incorporating environmental sustainability indicators into the design evaluation system will significantly strengthen the long-term usability and promotion potential of parent–child interactive seating in urban public spaces.

Meanwhile, this study is anchored in the context of parent-child interactive seating in children's parks and is structured around the following three core research questions:

Q1: Within diverse parent-child interaction scenarios in children's parks, how can the authentic needs of children across different age groups, along with those of their parents, be effectively identified, synthesized, and translated into design-relevant insights?

Q2: How can multiple methodologies—including Grounded Theory (GT), the Kano model, the Analytic Hierarchy Process (AHP), and Quality Function Deployment (QFD)—be systematically integrated to enable an end-to-end transition from user need identification to the formulation of design criteria?

Q3: While user satisfaction and experience are ensured, in what ways can sustainability principles be embedded throughout the life-cycle design and evaluation of parent-child interactive seating in children's parks?

LITERATURE REVIEW

The design of parent-child interactive seating in children's parks is explored in this study. To systematically review the existing body of research concerning user need identification, sustainable design, and integrated innovation models in this context, a structured literature review framework has been constructed, as illustrated in Fig. 1.

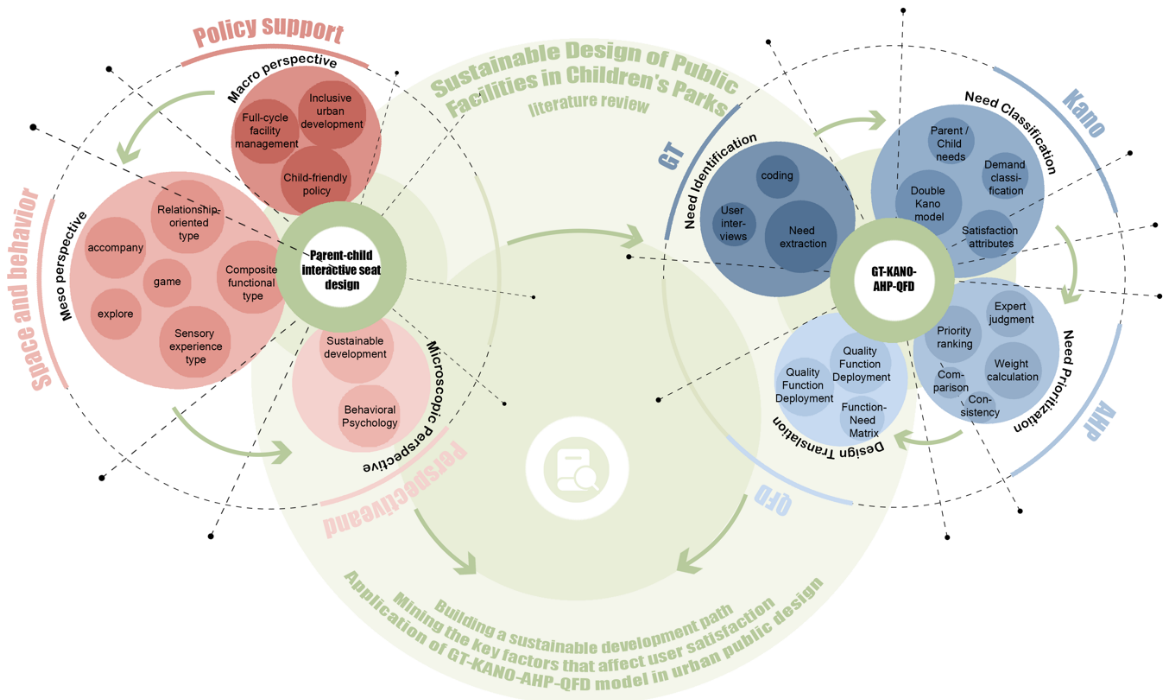

Fig. 1. Framework of the literature review

Overview of Research on Parent-child Interactive Seating in Children's Parks

Children's parks are defined as public spaces specifically intended to support children's play and social interaction, with an emphasis placed on fostering physical and cognitive development in outdoor settings (Zhang *et al.* 2022). As research into urban public spaces has advanced, attention has gradually shifted from macro-level spatial configurations to the micro-level design of public facilities—particularly seating—as a means of enhancing parent-child interaction (Yang *et al.* 2023). Seating is understood not only to fulfill its basic function of providing rest, but also to serve as a key medium for enabling shared presence and communication through ergonomic adaptation and ambient design (Tseng and Hsu 2019). Accordingly, "parent-child seating," which integrates play, companionship, and communication, has increasingly been recognized as a focal element in contemporary children's park design. This type of seating emphasizes dual-user adaptability, aiming to meet the participatory and safety needs of children during activities, while also accommodating parents' requirements for supervision, communication, and rest. It features multifunctional characteristics and entails specific demands for environmental adaptability and long-term durability.

In recent years, interdisciplinary research on public seating design has been steadily emerging. For instance, a study based on the Gumei Community Park in Shanghai proposed deriving sustainable design requirements from residents' perspectives and translating them—*via* life cycle assessment—into ten core sustainable design elements, such as ecological materials, emotional durability, and modular structures, thereby expanding the design logic of public seating from functional use toward environmental responsibility (Gulzar *et al.* 2025). Ali *et al.* (2025) introduced AI technology into the design process by developing an assistive system capable of automatically identifying material types and providing real-time feedback on carbon emissions, thus shifting public furniture design from a visual-centric approach to one driven by data perception. In addition, to enhance outdoor spatial adaptability, Gulzar *et al.* (2025) proposed a modular public seating design method, which improves multi-scenario spatial adaptability and user engagement through universal structures, functional assembly, and flexible configuration.

In practical applications, numerous urban projects have demonstrated successful user-centered design approaches. For instance, Malaysia's Putra Perdana Park optimized the ergonomic–aesthetic balance of its seating facilities based on visitor preference surveys, thereby enhancing the harmony between public amenities and the surrounding environment. In Hong Kong's urban parks, field observations revealed that flexible, dispersed, or circular seating arrangements facilitate better group eye contact, promoting parent–child communication. The renovation of Boston City Hall Plaza incorporated public feedback to install multiple sets of parent–child seating and interactive zones, achieving both functional integration and improved accessibility (Wikipedia contributors 2025). Similarly, micro street-space initiatives such as Parklets have shown that even under spatial constraints, high adaptability and long-term usability can be attained through user participation and functional transformation (Wikipedia contributors 2025).

Despite the growing body of related research and practice, systematic studies on "parent–child interactive seating" that integrate parent–child interaction needs with environmental sustainability goals within the specific context of children's parks remain relatively scarce. Therefore, establishing a user-centered, methodologically integrated research framework from a sustainability perspective can offer crucial theoretical guidance and engineering insights for the optimization of children's park facilities and the broader transformation of future public spaces.

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Sustainable Design within User Needs

User needs are defined as the explicit and implicit expectations articulated by users throughout a product's life cycle with regard to functionality, emotional value, and contextual use (Bloch 1995; Wang *et al.* 2017). Sustainable design, as embedded within user needs, emphasizes meeting these expectations while integrating environmental responsibility, resource efficiency, and life-cycle assessment principles. The goal is to enhance the social and environmental value of a product through structured design interventions (Daae and Boks 2015). When applied to seating design, this approach entails the fulfillment of user expectations alongside the pursuit of material efficiency, durability, and high adaptability. It has been demonstrated by an expanding body of research that the integration of user feedback throughout the design cycle results in seating solutions that are both functionally effective and environmentally sustainable (Sipahi and Sipahi 2024; Sierra-Pérez *et al.* 2021). For instance, in a study on public seating in Shanghai's Gumei community, Zhang and Sun (2024) translated user needs into design criteria and highlighted the essential role of co-creation workshops in identifying sustainability-oriented factors. Similarly, it has been argued by Alpak *et al.* (2020) that a multi-dimensional approach to seating design enhances user frequency and spatial interaction, thereby supporting urban spatial sustainability. In addition to traditional methods such as interviews and surveys, techniques including social co-creation, scenario simulation, and behavioral observation have been validated as effective means of identifying user needs. Meanwhile, Ragheb and Faragallah (2025) developed a user-oriented urban furniture evaluation system comprising four key dimensions: functionality, aesthetics, human factors safety, and environmental impact. This system collects feedback from both users and designers through questionnaires and expert reviews, effectively guiding the standardization and qualitative implementation of design practices. In addition, Yang *et al.*

(2024) proposed a comprehensive furniture life cycle design guideline and toolkit, encompassing 7 primary strategies, 21 sub-strategies, and 154 design recommendations, along with 41 detailed case studies of eco-friendly furniture. This toolkit supports designers in applying low-environmental-impact strategies at various stages of the design process.

In summary, the integration of user needs and sustainable design across the full product life cycle of seating has been widely recognized as a critical principle. Accordingly, the present study is situated within the specific context of parent-child interactive seating in children's parks, and a systematic research framework is proposed to achieve the coordinated optimization of user experience and sustainable development.

GT-KANO-AHP-QFD integrated innovation model

An integrated innovation model is defined as a comprehensive research approach in which multiple theoretical tools are combined to address complex design challenges. By embedding multi-perspective evaluation mechanisms into a structured process, such models are intended to enhance the efficiency and coherence of design-oriented decision-making (Poth 2018). In the present study, Grounded Theory (GT) is adopted as a bottom-up qualitative methodology for the in-depth exploration of user needs (Urquhart *et al.* 2010). The Kano model is applied to classify user needs, allowing for the identification of user sensitivity toward functional attributes and expectation-level differences (Xu *et al.* 2009). The Analytic Hierarchy Process (AHP) is utilized to assign relative weights to distinct user needs through a hierarchical decision-making structure, thereby supporting rational prioritization within the design process (Vargas 1990). Finally, Quality Function Deployment (QFD) is used to translate the "voice of the customer" into design specifications via the House of Quality, thereby facilitating the systematic realization of design intent (Chan and Wu 2002).

The applicability of integrated innovation models has been empirically validated across multiple disciplinary domains. In the domain of product design, a Kano-AHP-QFD integrated approach was applied by Liu *et al.* (2024) to evaluate the needs of breastfeeding mothers and infants, leading to enhanced product satisfaction and functional alignment. A fuzzy Kano-DEMATEL-AHP-QFD model was further employed by Neira-Rodado *et al.* (2020) to prioritize complex design requirements for hip surgery assistive devices for the elderly, thereby improving the adaptability and systemic coherence of health-related product design. In the service design domain, Kano, fuzzy AHP, and QFD were integrated by Haber *et al.* (2020) in the development of a product–service system. A mapping mechanism was established between customer requirements and engineering attributes, thereby enhancing service responsiveness and collaborative efficiency. A Kano-AHP-QFD framework was utilized by Pakizehkar *et al.* (2016) to restructure the customer service system of an Iranian bank, resulting in significant improvements in user satisfaction and process responsiveness. In the context of interaction design, an optimization strategy for in-vehicle control interfaces tailored to older adults was proposed by Liu *et al.* (2024), employing the Kano-AHP-QFD model to identify and reconfigure key factors affecting operational cognition and interaction efficiency, thereby addressing age-related usability challenges in a systematic manner. In a related study, the same integrated model was employed by Yang and Pan (see Fang *et al.* 2023) to optimize the user experience of a medication reminder app designed for elderly users. By translating user perceptions into critical design inputs, the model was validated as both scientifically rigorous and adaptable to digital product design targeting older populations.

In summary, integrated innovation models have been shown to be effective in synthesizing both qualitative and quantitative data, thereby facilitating the systematic identification of complex user needs and the optimization of product design processes. Accordingly, the present study is centered on the design of parent-child interactive seating in children's parks through the development of a GT-Kano-AHP-QFD integrated innovation model. The model is designed to be grounded in authentic user needs and to guide the exploration of a systematic design pathway for shared parent-child seating solutions.

METHODS

Research Framework

This study was guided by the Double Diamond model, a systematic design thinking framework that is intended to enhance the efficiency of exploration and validation in addressing complex design problems (Pandey *et al.* 2024). The model has been applied to guide the sustainable and innovative design of parent-child interactive seating in children's parks. It has been integrated with the GT-Kano-AHP-QFD approach to enable the in-depth extraction and translation of diverse user needs, thereby facilitating a balanced alignment between user demands and sustainability objectives. The overall research process has been structured in accordance with the Double Diamond framework, as illustrated in Fig. 2.

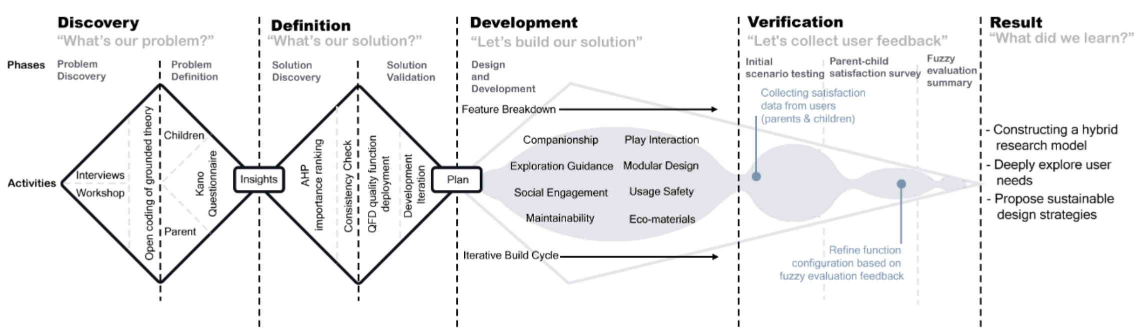


Fig. 2. Research framework based on the Double Diamond model

Phase 1 "Discovery": In the first phase, user needs and pain points associated with parent-child interactive seating in children's parks were preliminarily identified through workshops and several rounds of in-depth interviews. Open coding, grounded in the principles of Grounded Theory (GT), was applied to analyze the interview data qualitatively, enabling the initial categorization and synthesis of potential factors influencing the seating experience. Based on the GT findings, a Kano questionnaire was developed and administered to parent-child user groups. The collected data were then classified using the Kano model to provide empirical support for the subsequent stages of analysis.

Phase 2 "Definition": In the second phase, a hierarchical analysis model was developed based on the results of Kano classification. A judgment matrix was constructed, and a consistency check was performed to evaluate user needs comprehensively and quantify their relative importance. Subsequently, within the Quality Function Deployment (QFD) framework, user needs were systematically translated into corresponding design elements using the House of Quality, thereby enabling detailed analysis. Finally, an initial prototype was created to verify the completeness and logical soundness of the transformation pathway from user needs to design functions.

Phase 3 "Development": This phase was focused on functional decomposition and iterative refinement. Based on the findings from previous phases, multiple iterative cycles were carried out to incrementally optimize the structural configuration, dimensional parameters, and supplementary features of the seat. At each stage, performance assessments and user-fit evaluations were conducted to ensure continuous refinement. Ultimately, a viable design solution for parent-child interactive seating was developed.

Phase 4 "Validation": This phase was centered on the collection of authentic feedback from end users. Prototype testing was performed, during which users and experts were invited to participate in experiential evaluations. Satisfaction surveys were administered based on core design attributes identified through the QFD framework. Subsequently, a fuzzy comprehensive evaluation method was employed to conduct an integrated assessment of multiple dimensions of the parent-child interactive seating solution.

Finally, the entire research process was systematically reviewed and reflected upon by the research team. Informed by the principles of sustainable design, the innovative research pathways for parent-child interactive seating in children's parks were critically examined. Based on these insights, several directions for future research were outlined.

Research Methodology

Grounded Theory: Grounded Theory, originally proposed by Barney Glaser and Anselm Strauss in the 1970s, is regarded as a foundational qualitative research methodology (Glaser and Strauss 2017). Its core principle involves the suspension of prior assumptions, enabling the extraction of core concepts and categories through open, axial, and selective coding of primary data such as interview transcripts and textual materials (Glaser *et al.* 1968). Theoretical saturation is achieved through the use of techniques such as theoretical sampling, thereby contributing to the development of a robust explanatory framework. Throughout this iterative and cyclical process, new conceptual dimensions are continuously identified (Suddaby 2006; Tarozzi 2020). In the present study, user interview data were subjected to open coding in a dynamic and iterative manner. This approach enabled the in-depth identification of users' core needs regarding the design of parent-child interactive seating in children's parks, thereby establishing a solid theoretical foundation and empirical basis for subsequent quantitative analysis.

Kano Model: The Kano model, originally proposed by Noriaki Kano in the 1980s, has been widely employed to systematically analyze the relationship between user needs and user satisfaction (Chen and Chuang 2008). User requirements are classified based on their nonlinear influence on satisfaction (Jin *et al.* 2022). Responses are collected through questionnaires that assess both positive and negative perceptions of specific functions or attributes, and user needs are subsequently categorized *via* cross-analysis into six types: must-be, one-dimensional, attractive, indifferent, reverse, and questionable requirements (Xu *et al.* 2009; Kermanshachi *et al.* 2022). The Kano model allows for a more systematic understanding of user perceptions and supports the prioritization of product features to maximize satisfaction under limited resources. In this study, the actual needs of parent-child users were collected, systematically organized, and classified to inform the design direction of parent-child interactive seating in children's parks.

Analytic Hierarchy Process: The Analytic Hierarchy Process (AHP), originally proposed by Thomas L. Saaty in the 1970s, is a structured decision-making methodology in which complex problems are deconstructed into multi-level hierarchies for quantitative evaluation (Vaidya and Kumar 2006). At its core, AHP is used to convert subjective judgments into computable relative weights, which are subsequently employed to rank the overall importance of each element (Saaty 2008). By emphasizing the integration of qualitative judgments and quantitative calculations, AHP facilitates greater clarity in the evaluation of hierarchical criteria. Key steps involve the construction of a hierarchical model, development of a pairwise comparison matrix, calculation of relative weights, and consistency testing, which ultimately yield a prioritized ranking of user needs (Ho 2008; Saaty 2013). In this study, AHP was employed to assign relative weights and determine the priority of user requirements for parent-child interactive seating, based on prior classification results derived from the Kano model. This approach provided a scientific foundation for subsequent design decisions and clarified the relative importance of each identified requirement.

Quality Function Deployment: Quality Function Deployment (QFD), which was originally proposed by Yoji Akao in the late 1960s and early 1970s, is regarded as a systematic methodology for product development (Govers 1996). The QFD method emphasizes the explicit identification of user needs during the early stages of product development, followed by their structured deployment into design and production control phases to ensure alignment with user expectations (Mallon and Mulligan 1993; Cristiano *et al.* 2001). Its core tool, the "House of Quality," is employed to systematically relate customer requirements to technical characteristics. Importance ratings, correlation values, and other indices are calculated to translate user needs into actionable design elements (Chan and Wu 2005). QFD is essentially employed as a structured communication and decision-making tool that provides a rigorous analytical framework for managing complex product development processes (Wang 1999). In this study, a House of Quality was constructed based on prior results from the GT-Kano-AHP model, incorporating classified user requirements and their corresponding weights. This facilitated the systematic transformation of user needs into design specifications and offered quantitative support for subsequent design decisions.

Research Tools and Data Acquisition

NVivo 14.0 and SPSS 27.0 were employed as the primary software tools for qualitative and quantitative data analysis, respectively. NVivo, a professional qualitative analysis tool, was used to support a comprehensive coding procedure—including open, axial, and selective coding—that facilitated theoretical development and concept generation (Dhakal 2022). SPSS, widely adopted in statistical research, was utilized to conduct descriptive statistical analysis, reliability and validity tests, and Kano model classification. Additionally, it was integrated with decision-support tools such as AHP and QFD, thereby offering robust methodological support across the research process (Pallant 2020).

A progressive logic of "expert guidance – user participation – collaborative validation" was followed in data collection. The process was initiated with expert workshops to gather professional insights, followed by in-depth interviews with frontline users to identify latent needs. Subsequently, a structured questionnaire targeting parent-child users was administered to classify and validate user needs. Based on these results, the Analytic Hierarchy Process (AHP), Quality Function Deployment (QFD), and fuzzy comprehensive evaluation were subsequently applied to determine demand weights, establish technical mappings, and conduct comparative analysis, thereby contributing to the formation of a coherent data framework. Throughout the process, probabilistic sampling techniques were adopted to ensure the objectivity of the sample. Specifically, two expert workshops were conducted, both involving the same group of eight senior professionals (three landscape designers, two visual designers, and three industrial designers) to ensure coherence and comparability across the sessions. Professional insights regarding functionality, pain points, interactivity, and sustainability were elicited through brainstorming and co-creation sessions. These insights were subsequently used to develop a semi-structured interview protocol. Random interviews were conducted with 26 parent-child user pairs at Chaoyang Children's Park (Site A) and Taiyanggong Children's Park (Site B) in Beijing. In the quantitative phase, a Kano questionnaire was administered to parent-child participants. To ensure data quality, the questionnaire was limited to a completion time of 5 to 10 min; responses submitted in under two min were considered invalid. A reverse-coded item was embedded at the end of the questionnaire to assess response consistency. Responses that failed this check or were entirely duplicated were excluded. Stratified random sampling was employed for the formal survey, with "park location (A, B)" and "user type (parent, child)" used as stratification variables. Following the Kano-based classification, AHP was employed to quantify the relative importance of user needs. A panel of twelve experts—each with over ten years of experience in academia, design institutions, or park management—was invited to construct a judgment matrix using the Saaty 1–9 scale. Subsequently, QFD was employed to map the identified needs of both parents and children onto actionable design attributes. To ensure objectivity in scoring correlations, a 20-member evaluation panel was assembled, comprising 12 experts and 8 high-frequency users randomly selected from Sites A and B. This panel collaboratively assessed the strength of associations between user needs and technical attributes. Based on the scoring results, the first-level House of Quality was constructed, from which key design features were derived. Three design proposals were ultimately developed based on these prioritized attributes.

Ethical standards were rigorously upheld throughout the entire study. All participants were fully informed of the study's objectives and procedures prior to participation and were asked to provide written informed consent. All data were anonymized during both the data collection and analysis phases to ensure the confidentiality and protection of personal information.

EXPERIMENT

User Needs Identification Based on Grounded Theory

Expert workshop: Developing the interview framework

Grounded theory requires in-depth analysis of raw data to identify underlying patterns and associations, while ensuring that selected interviewees are representative and free from external interference (Belfrage and Hauf 2017). An extensive review of literature related to the design of public seating in park environments was conducted prior to the expert workshops. Preliminary research questions and design focal areas were formulated to offer theoretical support for the forthcoming expert discussions. Two interdisciplinary workshops were subsequently held, involving eight experienced experts: three landscape designers, two visual designers, and three industrial designers. The workshops centered on the topic of "parent-child interactive seating in children's parks," with discussions structured around three core themes: functionality, interactivity, and sustainability. Experts were selected based on the following criteria: (a) possessing no less than three years of practical or academic experience in public space facility design (including children's activity spaces and urban park seating) within related fields such as landscape design, industrial design, or visual design; (b) demonstrating domain relevance by having systematic theoretical knowledge and practical experience in at least two of the following areas: parent–child interaction and child development, safety and accessibility design standards, and sustainable materials; and (c) signing an informed consent form and agreeing to a confidentiality agreement, ensuring full participation in both workshops as well as the pre- and post-meeting evaluation sessions.

An in-depth analysis was conducted by experts of parent-child interaction patterns, spatial constraints, and design-related barriers observed in real-world park use scenarios. In the second phase, a preliminary multi-dimensional framework for semi-structured interviews was formulated by the research team based on expert consensus. Interview questions were designed from the perspectives of both parents and children to capture differentiated user experiences. The parent interview protocol focused on five key dimensions: (a) usage scenarios, (b) spatial adaptability and functional needs, (c) parent-child interaction and communication, (d) environmental perception, and (e) emotional experience. The children's interview protocol was organized around the following dimensions: (a) daily activity preferences, (b) physical comfort, (c) playfulness and engagement, (d) interaction and companionship, and (e) aesthetic preferences. The interview outline was refined through iterative review to ensure alignment with professional standards and practical applicability. This process was intended to facilitate the effective implementation of semi-structured interviews by targeting the core needs associated with parent-child interactive seating in real-world contexts. Details are provided in Table 1.

Table 1. Semi-Structured Interview Outline

Interviewee Group	No.	Interview Question
Parent Users	1	At what times or in what situations do you typically bring your child to the park?
	2	What aspects of the current park seating do you find most satisfactory or dissatisfactory?
	3	What kinds of interactions or activities do you usually engage in with your child while seated?
	4	In terms of functions or operations, what additional features do you think should be added?
	5	Are there any other ideas or needs regarding parent-child interactive seating that you consider important?
Child Users	1	What kind of seating do you like the most in the park?
	2	When you sit on a bench with your parents, what do you usually do together?
	3	If you could design your own bench, what features would you add?
	4	How would you like the bench to be designed to make it easier for you and your parents to play together?
	5	What colors or shapes of benches do you like the most?

User interviews: eliciting latent and explicit needs

To investigate both explicit and implicit needs related to parent-child interactive seating in real-world contexts, semi-structured interviews were conducted with key user groups—specifically, parents and children—within children's park environments. Semi-structured interviews are widely employed as a primary data collection method within the grounded theory approach in qualitative research. This method facilitates the identification of underlying user needs while maintaining alignment with the central research objective (Foley *et al.* 2021).

Beijing, as a representative example of China's urbanization process, is characterized by a diverse range of children's parks, offering a rich context for investigating parent-child interactive public facilities (Xiaoli *et al.* 2013). Accordingly, two representative parks in Beijing—Chaoyang Children's Park and Taiyanggong Children's Park—were selected as fieldwork sites. Participants were recruited through on-site random intercept interviews. To ensure the representativeness of the sample, specific inclusion criteria were established for participant selection: (a) parents were required to have used children's parks regularly for over one year; (b) parents were required to have spent significant time in park rest areas engaging in interactive or companion activities with their children; and (c) children were required to be between the ages of 7 and 12, possess basic verbal communication skills, and be capable of articulating their preferences, experiences, and ideas under the guidance of a researcher. The required sample size was calculated using G*Power (α = 0.05, power = 0.80), assuming a medium-to-large effect size ($f^2 \approx 0.25$–0.35), resulting in a minimum of 24 participants. In addition, the point at which no new concepts emerged during the open coding process was used as a criterion for data saturation. Based on these criteria, a total of 26 participants were recruited. The demographic characteristics of the final sample are summarized in Table 2.

Table 2. Distribution of Respondent Characteristics

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	11	42.3
	Female	15	57.7
Age Group	7–9 years (Younger Children)	3	11.5
	10–12 years (Older Children)	5	19.2
	28–35 years	11	42.3
	36–45 years	7	26.9
Role Type	Parent	18	69.2
	Child	8	44.4
Park Visit Frequency	High Frequency (⩾ once/week)	14	53.8
	Medium Frequency (⩾ once/month)	8	30.8
	Low Frequency (Irregular visits)	4	15.4

All interviews were conducted in a one-on-one format under the guidance of the research team, with each session lasting approximately 20 to 30 min. Informed consent was obtained from all participants prior to the full audio recording of each session. After completion, all recordings were transcribed verbatim into textual data, which served as the foundational dataset for subsequent coding and analysis.

Semantic coding: Extracting core categories

Open coding is recognized as the initial stage of grounded theory research and is employed to systematically conceptualize raw qualitative data. By identifying key meaning units within the textual data, core categories are extracted from the original content (Cascio *et al.* 2019).

In this study, open coding was conducted using NVivo 14.0, a qualitative data analysis software, to process the transcribed interview texts. To ensure objectivity and analytical rigor, independent analyses were conducted by three researchers, and the coding results were subsequently cross-validated.

A total of 29 initial concepts (a1 to a29) and 8 core categories (A1 to A8) were identified as a result of the semantic coding process. The detailed coding results are summarized in Table 3.

Theoretical saturation test

Grounded theory research is inherently characterized as an iterative process involving conceptual abstraction, theoretical sampling, and the progressive refinement of data derived from primary sources. Each data entry is required to be systematically analyzed to identify emerging categories, with supplementary data being collected iteratively until no further categories are observed in the analytical process. This stage, referred to as theoretical saturation, signifies the threshold at which a theoretical model is deemed constructible (Liu and Zhang 2024). In the current study, interview data collected from all 26 participants were subjected to rigorous systematic coding and analysis. By the time the coding process reached the 23rd participant, all identified concepts had been accommodated within the existing theoretical framework, suggesting that the prerequisites for model construction had been satisfied. To further enhance the methodological rigor and completeness of the study, interview data from three additional participants were subsequently incorporated into the coding process. As no additional categories or novel concepts emerged during this phase, the achievement of theoretical saturation was thereby confirmed.

Kano-Based Classification of User Needs

Questionnaire Construction

Based on the results of open coding from the grounded theory analysis, a Kano-based measurement scale of user satisfaction was constructed to systematically classify functional attributes according to user perceptions (Cavacece *et al.* 2025). The questionnaire was structured around a dual-dimensional evaluation mechanism, in which each functional attribute was assessed from two perspectives by respondents: a positive dimension reflecting satisfaction when the function is present, and a negative dimension capturing dissatisfaction when the function is absent.

To enhance data reliability, a five-point Likert scale was employed, with 1 denoting "not important at all" and 5 denoting "extremely important." The five-point format was preferred due to its moderate difficulty, cognitive efficiency, and broad acceptance in survey-based research (McKelvie 1978). The complete questionnaire items are presented in Table 4.

Table 3. Open Coding Results Based on Grounded Theory

Core Category	Initial Concept	Original Quote
A1. Playfulness	a1. Rotating Function	My child loves chairs that can spin; it feels like riding a small amusement park ride. (p1)
	a2. Hidden Mechanism	I'd like to install a small mechanism on the side of the chair—pressing it could release bubbles or make a sound. (p4)
		If toys could be hidden underneath the chair, kids would definitely be curious and explore. (p6)
	a3. Assembling Games	I want to turn the chair into a 'castle' by stacking blocks on it. (p5)
		If the chair can be assembled freely like building blocks, it could be changed into many forms. (p6)
		If it's designed for building, it could develop children's creativity and collaboration skills. (p24)
		We enjoy role-playing as engineers to construct 'castles' and 'mazes'. (p15)
	a4. Painting Space	Kids like painting on chairs, but it needs a surface that can be cleaned. (p12)
		If I paint flowers and animals on it, the chair will look really nice. (p25)
	a5. Music and Light Effects	If there are lights, it will look beautiful at night. (p3)
		If music can be played, we'll feel more relaxed during breaks.
A2. Safety	a6. Safety Handrails	My child really likes it—if there are handrails, I won't worry about them slipping and getting hurt. (p10)
		Handrails are especially important for small kids; they help them stand safely. (p12)
		When I hold onto the handrail, I'm not afraid of falling. (p21)
	a7. Anti-slip Design	If the seat surface is made of non-slip material, children are less likely to fall even after it rains. (p15)
	a8. Structural Stability	The legs of the chair must be stable; otherwise, even slight movements by the child may cause it to shift or tip. (p17)
		Kids often stand on the chair, so it must be stable enough to support that. (p23)
	a9. Emergency Call System	What I worry about most is if a child suddenly feels unwell. If there were an emergency call button on the chair to instantly contact staff, that would be ideal. (p5)
		Elderly caregivers would feel more at ease taking children out if emergencies could be immediately reported to park security or the police. (p7)
A3. Interactivity	a10. Group Integration	Sometimes the three of us want to sit together and chat, but there isn't enough space for that. (p10)
		When grandparents join us, we hope there are enough seats arranged in a circle so everyone can talk together. (p26)
	a11. Face-to-Face Layout	Sitting face-to-face makes it easier to see the child's expressions and communicate. (p2)
		I like playing rock-paper-scissors with my dad—sitting across from him makes it more convenient. (p9)
		It's best to sit facing each other for reading picture books or chatting, as the eye contact is better. (p18)

	a12. Game Zone	It would be great to have some mini game stations on or beside the chair so that parents and children can play together. (p4)
A4. Aesthetics	a13. Thematic Styling	If it's designed like a fairytale castle or forest animal, children will be more eager to sit on it. (p1)
		I love dinosaur shapes—they look super cool! (p27)
	a14. Bright Colors	Pink and purple look really pretty. I'd want to sit there and take pictures. (p17)
		Children tend to prefer bright colors because they look more lively. (p19)
		Bright colors are also easier to spot in the park environment. (p21)
	a15. Decorative Elements	If you add cartoon stickers or small figurines, kids can imagine all kinds of stories. (p2)
		Decorations could incorporate educational or cultural elements to help children learn. (p11)
	a16. Visual fusion	It looks photogenic too, so I'd often post pictures on social media. (p10)
		If it blends with the grass, it feels like an adventure in the forest. (p14)
		If it aligns with the overall park style, it can also serve as a visual attraction. (p4)
A5. Practicality	a17. Attached Tabletop	A small table would let children draw or place their snacks. (p9)
		We occasionally have picnics, so a tabletop would be very practical. (p20)
		With a table, we could set up building blocks or play card games. (p22)
	a18. Storage Space	When going out with kids, we usually carry many items, so having hooks is very convenient. (p10)
		Hooks are really useful—they prevent our belongings from getting dirty. (p15)
		It's convenient for placing water bottles or toys, so we don't have to carry them all the time. (p28)
	a19. Multi-scene Fit	I like to move it under the shade for block play so it doesn't get too sunny. (p12)
		If it can be moved between different zones, it would be suitable for reading, resting, and playing. (p14)
	a20. Height Adjustment	If the child sits comfortably, it also makes things easier for the parents. (p12)
		If it can be adjusted, it would make changing clothes much easier. (p20)
A6. Comfort	a21. Elastic Design	If the seat is cushioned, prolonged sitting does not cause back pain, and children tend to like it as well. (p4)
	a22. Ergonomics	When the backrest is ergonomically curved to fit the body, back soreness is less likely to occur. (p10)
		For children with shorter legs, overly deep seats can be uncomfortable. (p17)
		It would be ideal if the design could accommodate users of different body sizes. (p20)
	a23. Temperature Control	In summer, the seat becomes too hot for children to sit on. (p3)
		In winter, the seat feels very cold as soon as I sit down. (p25)
A7. Emotional	a24. Social Atmosphere	When several families sit together, they not only talk about parenting but also make new friends. (p13)
		It feels like a small community where everyone gathers to share their experiences. (p18)
		It feels lively when everyone sits together to enjoy snacks. (p22)
	a25. Memory of	This place feels like a 'secret base' where friends agree to meet up. (p4)

	Belonging	My child says, 'This is our seat,' and insists on sitting in the same one every time we come. (p12)
	a26. Emotional Immersion	When sitting with my child, I forget about work-related stress and become more engaged in spending time together. (p5)
A8. Sustainability	a27. Recyclable Materials	As long as it is durable and reliable, I would support the use of environmentally friendly materials. (p19)
		In this way, the amount of waste on our planet could be reduced. (p24)
		Instilling environmental awareness in children should also be considered a form of education. (p26)
	a28. Modular Replacement	If damaged parts can be replaced individually, overall material waste could be minimized. (p13)
		I hope this chair will still be around when I grow up. (p19)
	a29. Green Energy	If a child rocks the chair, the motion could be converted into electricity to power a small light, thereby teaching the concept of energy cycling. (p2)
		By stepping on a pedal attached to the chair, electricity could be generated—it would feel like becoming a mini power plant! (p7)
		If the chair were equipped with a solar panel to store energy during the day and light up an LED lamp at night, it would serve as a form of environmental education. (p15)

Table 4. Kano Questionnaire Format

User Requirement	Question	Dislike	Can Tolerate	Neutral	Accept as Expected	Like
The core functions of parent-child interactive seating in children's parks	If the seating is equipped with this function, what is your attitude?	□	□	□	□	□
	If the seating is not equipped with this function, what is your attitude?	□	□	□	□	□

Data collection

This study employed offline questionnaire surveys for data collection. The survey was conducted simultaneously from January 5 to January 20, 2025, in two representative sample areas: Chaoyang Children's Park and Taiyanggong Children's Park in Beijing. Using a stratified random sampling method, the research team distributed closed-ended questionnaires face-to-face to parents and children present at the sites, aiming to systematically gather user feedback and evaluations regarding the functions of parent–child interactive seating. A total of 215 questionnaires were distributed, with 130 at Chaoyang Children's Park and 85 at Taiyanggong Children's Park. Ultimately, 174 valid responses were obtained, 118 from Chaoyang and 56 from Taiyanggong. By targeting representative urban parent-child recreational spaces and employing a rigorously designed questionnaire, diverse empirical data were generated, providing a solid basis for subsequent statistical analysis and model validation.

Reliability and validity testing

Based on the user survey data, the research team conducted a comprehensive reliability and validity assessment using SPSS 27.0, with detailed results presented in Table 5. First, the internal consistency of the questionnaire was evaluated by calculating the Cronbach's α coefficient to assess the overall reliability of the scale (Hair *et al*. 2014). The results showed a Cronbach's α of 0.820, exceeding the recommended threshold of 0.7, indicating a high level of internal consistency and measurement reliability. To further assess the structural validity of the data under the proposed theoretical model, the six-dimensional evaluation framework was tested using the Kaiser–Meyer–Olkin (KMO) measure and Bartlett's test of sphericity. The analysis revealed a KMO value of 0.633, surpassing the acceptable threshold of 0.6, and a Bartlett's test p-value of 0.00, well below the 0.05 significance level, making it possible to reject the null hypothesis that there was no effect. These results confirm the quality and representativeness of the dataset, providing a solid empirical foundation for subsequent multi-factor analyses.

Table 5. Overall Questionnaire Reliability and Validity Test Results (n = 174)

Test Type	Index	Value
Cronbach Reliability Test	Cronbach's α Coefficient	0.820
	KMO Value	0.633
Bartlett's Sphericity Test	Bartlett's Test Value	6354.786
	Degrees of Freedom (DF)	1653
	p-value	0.00

Kano classification results

A statistical analysis was conducted to categorize the attribute types of each evaluative indicator according to the Kano model, with detailed classification outcomes provided in Table 6. The final categorization of each functional attribute was derived from the most frequently selected demand category by respondents. The analysis revealed that all demand items were distributed across the six Kano categories: required attribute (M), desired attribute (O), charming attribute (A), indifferent attribute (I), reverse attribute (R), and questionable attribute (Q). This distribution suggests that the evaluation indicator system was well-designed, exhibiting strong discriminative validity and representative-ness.

Table 6. Kano Classification Results

No.	Percentage (%)						Type	SI (%)	DSI (%)
	A	O	M	I	R	Q			
A1. Rotating Function	16.09	27.59	13.79	41.95	0.57	0.00	I	43.93	-41.62
A2. Hidden Mechanism	12.07	29.89	10.92	44.83	0.00	2.30	I	42.94	-41.76
A3. Assembling Games	12.64	20.69	48.28	18.39	0.00	0.00	M	33.33	-68.97
A4. Painting Space	52.87	19.54	11.49	16.09	0.00	0.00	A	72.41	-31.03
A5. Music and Light Effects	31.03	17.24	13.79	37.93	0.00	0.00	I	48.28	-31.03
A6. Safety Handrails	25.86	14.94	42.53	16.09	0.57	0.00	M	41.04	-57.80
A7. Anti-slip Design	24.14	45.98	16.09	13.79	0.00	0.00	O	70.11	-62.07
A8. Structural Stability	25.29	17.24	14.94	40.80	0.00	1.72	I	43.27	-32.75
A9. Emergency Call System	12.64	12.64	50.57	24.14	0.00	0.00	M	25.29	-63.22
A10. Group Integration	19.54	11.49	47.13	21.84	0.00	0.00	M	31.03	-58.62
A11. Face-to-Face Layout	36.78	18.39	19.54	25.29	0.00	0.00	A	55.17	-37.93
A12. Game Zone	49.43	16.67	22.99	10.34	0.57	0.00	A	66.47	-39.88
A13. Thematic Styling	16.09	43.68	26.44	13.79	0.00	0.00	O	59.77	-70.11
A14. Bright Colors	13.79	14.94	28.74	41.38	0.00	1.15	I	29.07	-44.19
A15. Decorative Elements	10.34	18.39	24.14	46.55	0.57	0.00	I	28.90	-42.77
A16. Visual fusion	16.09	28.16	39.66	14.37	0.00	1.72	M	45.03	-69.01
A17. Attached Tabletop	16.67	43.10	28.16	12.07	0.00	0.00	O	59.77	-71.26
A18. Storage Space	12.07	44.25	29.89	13.79	0.00	0.00	O	56.32	-74.14
A19. Multi-scene Fit	48.85	14.94	23.56	12.64	0.00	0.00	A	63.79	-38.51
A20. Height Adjustment	17.82	21.26	45.40	14.94	0.57	0.00	M	39.31	-67.05
A21. Elastic Design	10.92	47.70	28.74	12.64	0.00	0.00	O	58.62	-76.44
A22. Ergonomics	18.97	20.69	40.23	17.24	0.57	2.30	M	40.83	-62.72
A23. Temperature Control	51.72	13.79	21.84	12.64	0.00	0.00	A	65.52	-35.63
A24. Social Atmosphere	9.77	14.94	21.26	53.45	0.57	0.00	I	24.86	-36.42
A25. Memory of Belonging	13.79	51.15	25.29	9.77	0.00	0.00	O	64.94	-76.44
A26. Emotional Immersion	19.54	39.08	26.44	14.94	0.00	0.00	O	58.62	-65.52
A27. Recyclable Materials	20.11	23.56	39.66	16.67	0.00	0.00	M	43.68	-63.22
A28. Modular Replacement	38.51	20.11	25.29	14.94	0.00	1.15	A	59.30	-45.93
A29. Green Energy	54.02	13.22	24.14	8.62	0.00	0.00	A	67.24	-37.36

Furthermore, a comparative analysis of the functional attributes was performed according to the Kano classification table, and the Satisfaction Index (SI) and Dissatisfaction Index (DSI) were subsequently computed to quantify their respective influence on user perception. The corresponding formulas are as follows:

$$SI = \frac{(A' + O')}{(A' + O' + M' + I')} \tag{1}$$

$$DSI = -\frac{(O'+M')}{(A'+O'+M'+I')} \quad (2)$$

These coefficients reflect the degree to which each indicator is sensitive to user satisfaction. A higher SI value demonstrates that the presence of a given feature leads to a significant increase in user satisfaction, whereas a lower DSI value implies that its absence is likely to cause dissatisfaction (Deng *et al.* 2023). A detailed visualization of the analysis is provided in Fig. 3.

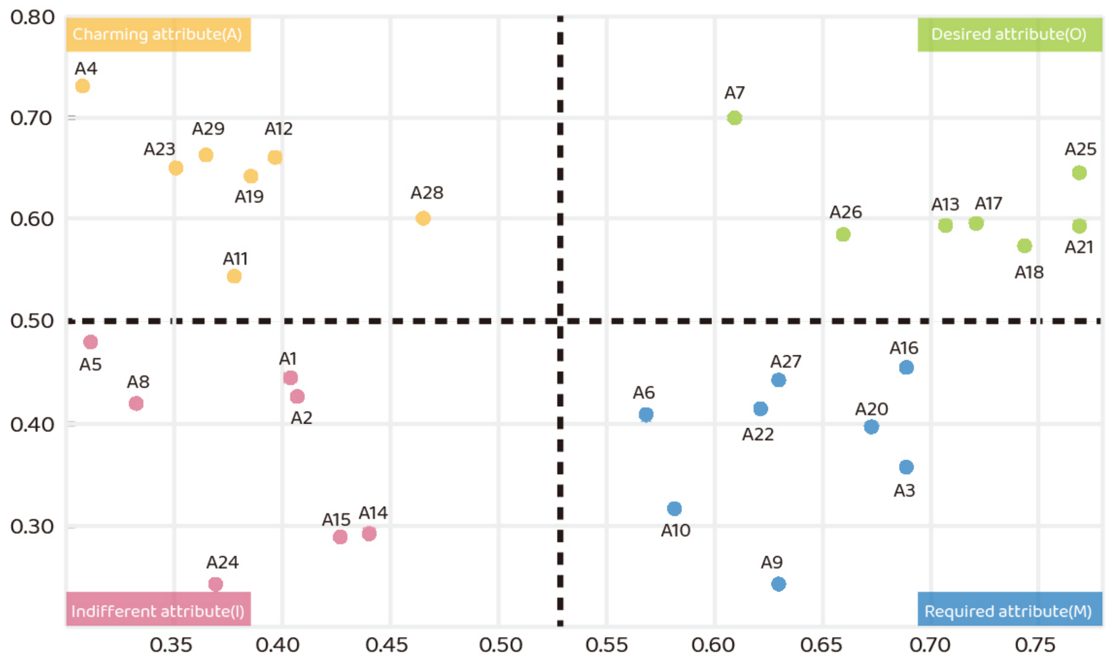


Fig. 3. Better-worse analysis results

User Requirement Weight Calculation and Ranking Based on AHP

Following the construction of the hierarchical model of user needs, the Analytic Hierarchy Process (AHP) was employed to construct a pairwise comparison matrix, thereby facilitating a systematic decomposition of the multi-criteria decision-making problem. A consistency check of the judgment matrix was subsequently conducted to assess logical consistency and to derive the relative importance weights of user needs. This procedure was designed to minimize decision-making bias and to strengthen the reliability of the evaluation outcomes.

Hierarchical structure model construction

Prior to the formal implementation of AHP-based quantitative weighting, a systematic hierarchical decomposition of user needs was carried out to clarify the evaluation objectives and the corresponding weight allocation process. Drawing upon the Kano-based classification of user needs identified in the prior phase of the study, a three-tier hierarchical model was established, comprising a goal level, a criteria level, and a sub-criteria level.

As illustrated in Fig. 4, the goal level was focused on the “core needs of parent-child interactive seating in children's parks,” thereby defining the primary decision-making objective of the study. At the criteria level, three key demand categories from the Kano model—attractive (A), one-dimensional (O), and must-be (M) requirements—were integrated, as they exert a positive influence on user satisfaction. This configuration retains the Kano model's theoretical advantage in addressing the asymmetric nature of user satisfaction responses, while deliberately excluding indifferent (I) and reverse (R) needs from the evaluation framework to improve the accuracy and discriminative validity of weight allocation (Madzík *et al.* 2024). At the sub-criteria level, 22 representative functional attributes were mapped individually. Through this AHP-based hierarchical structure, a systematic linkage was established between the user satisfaction model and the functional attribute system, thereby offering a computable structural foundation for subsequent quantitative weight assignment.

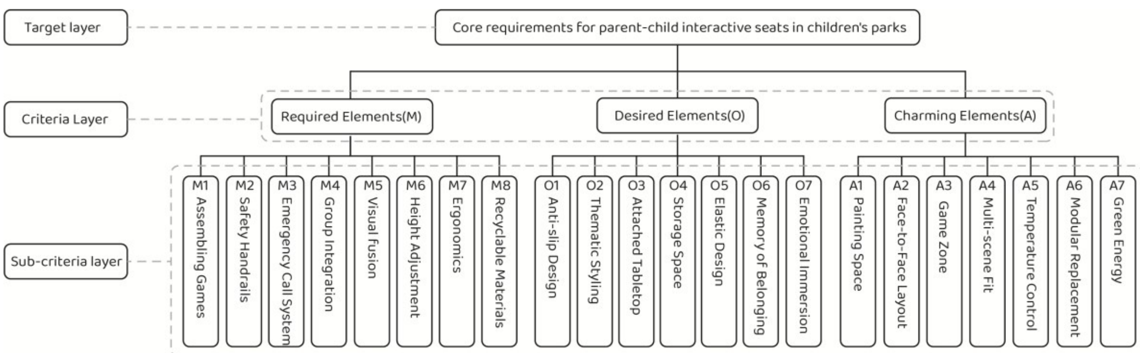


Fig. 4. User needs hierarchical analysis model

Construction of judgment matrix and weight calculation

After the hierarchical structure model was established, a panel of 12 experts specializing in landscape design, visual design, and industrial design was invited to perform pairwise comparisons of the indicators at each level using the Saaty 1–9 scale. Based on this approach, the judgment matrix was developed using the following formula:

$$A = (a_{ij})_{n\times n} \tag{3}$$

where a_{ij} denotes the relative importance of indicator *i* with respect to indicator *j*, satisfying the following conditions: $a_{ij}>0$， $a_{ii}=1$，

$$a_{ij} = \frac{1}{a_{ij}}, (i,j = 1,2,3,\dots,n). \tag{4}$$

To determine the weight vector ω, the principal eigenvalue λ_{max} of the matrix was calculated through the following steps:

First, the columns of matrix A were normalized by column-wise division:

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} (i,j = 1,2,3,\dots,n) \tag{5}$$

Second, the rows of the normalized matrix were aggregated

$$c_i = \sum_{j=1}^{n} b_{ij}\ (i,j = 1,2,3,\dots,n) \tag{6}$$

Finally, the weight ω_i (i=1, 2, 3, …, n) for each indicator was derived by normalizing the vector C = (c_1, c_2, ..., c_n):

$$\omega_i = \frac{c_i}{\sum_{i=1}^{n} c_i} (i = 1,2,3,\dots,n) \tag{7}$$

Based on Eq. 3, the judgment matrix for the criteria level of user needs concerning parent-child interactive seating in children's parks was first developed (Table 7).

Table 7. Judgment Matrix at the Criteria Level

Index	M	O	A	Relative Weight
M	1	3	5	0.6333
O	1/3	1	3	0.2605
A	1/5	1/3	1	0.1062

Using Eqs. 4 through 7, the corresponding relative weights were calculated. Following the same procedure, judgment matrices were constructed for the 22 functional attributes at the sub-criteria level, and their local weights were calculated (Table 8). Finally, the overall weight of each functional attribute was obtained by multiplying its local weight by the weight of its corresponding criterion and then normalizing the result. Based on these computed weights, all indicators were prioritized accordingly.

Table 8. Judgment Matrix at the Sub-Criteria Level

Primary Index	Secondary Index	Judgment Matrix								Relative Weight
M	M1, Assembling Games	1	5	3	2	1	5	2	5	0.2348
	M2, Safety Handrails	1/5	1	1	1/3	1/5	2	1/3	1/2	0.0496
	M3, Emergency Call System	1/3	1	1	1/3	1/5	1	1/5	1/4	0.0445
	M4, Group Integration	1/2	3	3	1	1/3	3	1	3	0.1293
	M5, Visual fusion	1	5	5	3	1	4	5	3	0.2773
	M6, Height Adjustment	1/5	1/2	1	1/3	1/4	1	1/3	1/2	0.0424
	M7, Ergonomics	1/2	3	5	1	1/5	3	1	4	0.1427
	M8, Recyclable Materials	1/5	2	4	1/3	1/3	2	1/4	1	0.0794
A	A1, Painting Space	1	3	1/3	2	5	1/3	3		0.1494
	A2, Face-to-Face Layout	1/3	1	1/4	1/5	3	1/5	2		0.069
	A3, Game Zone	3	4	1	4	5	3	4		0.3337
	A4, Multi-scene Fit	1/2	5	1/4	1	3	1/2	3	/	0.1303
	A5, Temperature Control	1/5	1/3	1/5	1/3	1	1/5	1/4		0.0345
	A6, Modular Replacement	3	5	1/3	2	5	1	3		0.2158
	A7, Green Energy	1/3	1/2	1/4	1/3	4	1/3	1		0.0673
O	O1, Anti-slip Design	1	1/3	1/2	2	1/7	1/4	1/3		0.0514
	O2, Thematic Styling	3	1	3	4	2	1/2	1		0.1647
	O3, Attached Tabletop	2	1/3	1	3	1/3	1/3	1/4		0.0733
	O4, Storage Space	1/2	1/4	1/3	1	1/6	1/7	1/7	/	0.0304
	O5, Elastic Design	7	1/2	3	6	1	1/5	1/3		0.1485
	O6, Memory of Belonging	4	2	3	7	5	1	5		0.3472
	O7, Emotional Immersion	3	1	4	7	3	1/5	1		0.1846

As illustrated in Fig. 5, the results of the comprehensive weight analysis revealed that users exhibited a strong preference for sensory integration and contextual engagement functions among the demand elements for parent-child interactive seating in children's parks. Visual fusion was ranked highest (weight: 0.1766), reflecting the emphasis placed on the aesthetic value of its harmony with the surrounding park environment. Assembling games (weight: 0.1487) and ergonomics (weight: 0.0904) were ranked second and third, respectively, highlighting the significance of play engagement and physical comfort as key design drivers. Subsequent priorities—such as game zone and group integration—belong to the category of structural interaction and collaborative use, suggesting a user preference for multifunctional seating that promotes family interaction and co-play. In contrast, conventional features—such as storage space (weight: 0.0322), anti-slip design (weight: 0.0555), and attached tabletop (weight: 0.0078)—were assigned relatively low overall weights. This suggests that such foundational features are now commonly perceived as standard expectations, thereby providing limited differentiation in user preference.

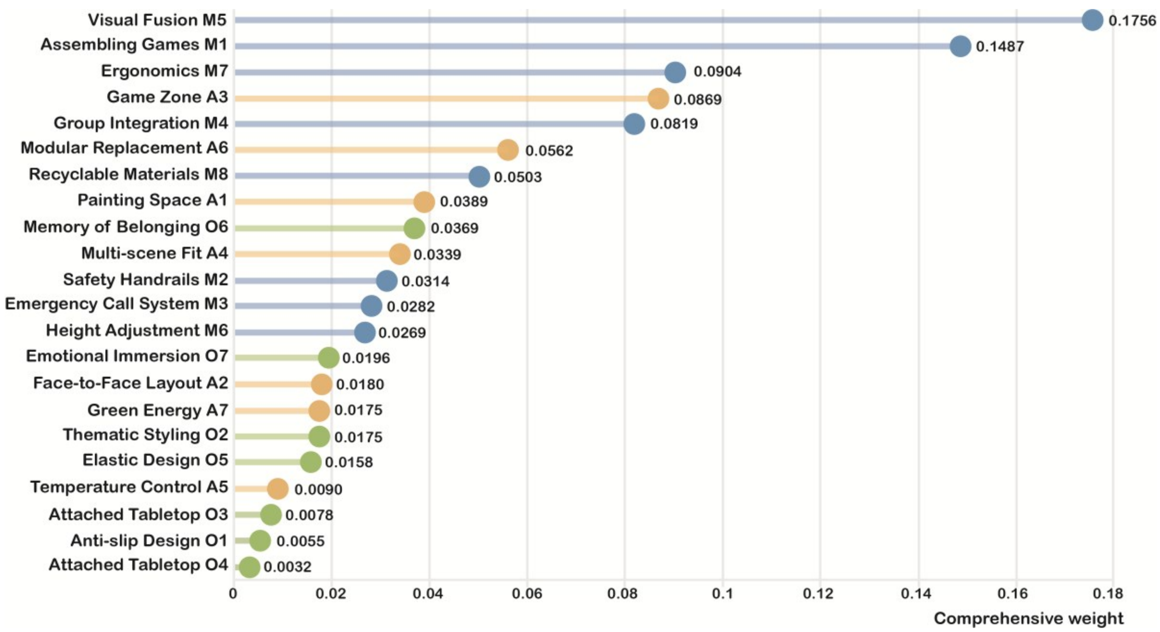


Fig. 5. Ranking of user needs hierarchical analysis results

These findings offer explicit prioritization guidance for the design of parent-child interactive seating, with emphasis placed on visual experience, play-based configuration, and structural safety, while incorporating principles of environmental sustainability. Beyond ensuring basic functional performance, the transition from purely physiological use to contextually enriched and family-centered collaborative experiences is expected to further improve user satisfaction and increase actual usage frequency.

Consistency verification

After the weights had been derived from each level of the judgment matrices, a consistency check was conducted to assess the logical consistency of the expert evaluations and to ensure that the resulting weight system was statistically valid (Wang *et al.* 2013).

First, the principal eigenvalue (λ_{max}) of the judgment matrix was calculated using the eigenvector method as follows,

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(P\omega)_i}{n\omega_i} (i, j = 1,2,3, \dots, n) \tag{8}$$

where $(P \cdot \omega)_i$ is defined as the i-th component of the vector resulting from the multiplication of the judgment matrix A and the weight vector ω, while *n* denotes the order of the matrix.

Next, the Consistency Index (CI) was calculated using Eq. 9.

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{9}$$

Subsequently, the Consistency Ratio (CR) was determined by dividing the CI by the Random Index (RI), as proposed by Saaty and shown in Eq. 10.

$$CR = \frac{CI}{RI} \tag{10}$$

A CR value less than 0.1 is considered acceptable, indicating that the expert judgments are sufficiently consistent and that the derived weights can serve as a reliable basis for subsequent decision-making (Padilla-Garrido *et al.* 2014).

In accordance with the above method, consistency verification was performed for both the criteria and sub-criteria levels, as shown in Table 9. All calculated CR values were found to be below 0.1, confirming that the data satisfied the consistency criteria. These results demonstrate strong agreement among expert evaluations, indicating that the weighting system is both statistically and logically robust and can serve as a quantitative foundation for the subsequent QFD analysis.

Table 9. Consistency Test Results

Index	P	M	O	A
λ max	3.039	8.558	7.733	7.751
CI	0.019	0.080	0.122	0.125
RI	0.520	1.410	1.360	1.360
CR	0.037	0.056	0.090	0.092

QFD-Based Transformation of Design Requirements

Requirement-to-technical feature translation

Following the prioritization of user needs, the Quality Function Deployment (QFD) method was employed to systematically transform user requirements into implementable technical features, thereby establishing a bidirectional linkage between user needs and technical solutions. QFD is designed to ensure that user needs are systematically identified, prioritized, and incorporated into the early stages of product development through a structured methodology, thereby offering a well-defined path for functional realization (Hu *et al.* 2024).

To ensure the scientific rigor of the QFD analysis, the top 50% of user needs—as determined by the weighting results from the AHP model—were identified and used as core inputs for subsequent technical mapping, resulting in 11 high-priority requirements. This strategy not only adheres to the logic of the Pareto principle in optimizing user satisfaction, but it also reduces the structural complexity of the House of Quality, thereby improving the clarity and efficiency of the evaluation process (Dunford *et al.* 2014). To ensure alignment between technical attributes and user needs, a preliminary set of potential technical features for parent-child interactive seating was derived from prior user interviews, expert workshops, and case analyses.

Building on this foundation, a panel of 12 experts from diverse fields was convened to form an independent review committee, which conducted multiple rounds of relevance assessments on the proposed mappings. After multiple rounds of evaluation and cross-validation, a final set of 11 key technical features was validated and finalized by the research team, as presented in Table 10.

Table 10. Parent–Child Interaction Needs–Technical Feature Conversion Table

Target Layer	Criteria Layer	Sub-criteria Layer	Technical Features
Parent-Child Interactive Seating Design in Children's Parks	M	M5 Visual fusion	D1 Blurred Boundaries and Environmental Integration
		M1 Assembling Games	D2 Block-Based Construction
		M7 Ergonomics	D3 Double-Layer Seating – Shared Backrest Ergonomic Structure
		M4 Group Integration	D4 Dialogue-Oriented Layout
		M8 Recyclable Materials	D5 Recycled HDPE and Regenerated Plastic Composite Materials
		M2 Safety Handrails	D6 Multi-Sensory Safety Handrail System
	O	O6 Memory of Belonging	D7 Parent-Child Interaction Achievement Badge System
	A	A3 Game Zone	D8 Cooperative Parent-Child Game Interaction
		A6 Modular Replacement	D9 Standardized Modular Components
		A1 Painting Space	D10 Smart Writable Coating Panel
		A4 Multi-scene Fit	D11 Lightweight Movable Base Seat

Construction of the House of Quality (HOQ)

The House of Quality (HOQ), a central tool in Quality Function Deployment (QFD), is composed of three primary components: the requirement–technical matrix, the correlation matrix, and the technical interaction matrix. These components are employed to evaluate and align the strength of association and feasibility between user requirements and corresponding technical features (Chen *et al.* 2012). This structured analytical tool enables the quantitative assessment of how each technical pathway contributes to fulfilling specific user requirements, while also allowing for the identification of priorities and interdependencies among various technical strategies in practical application.

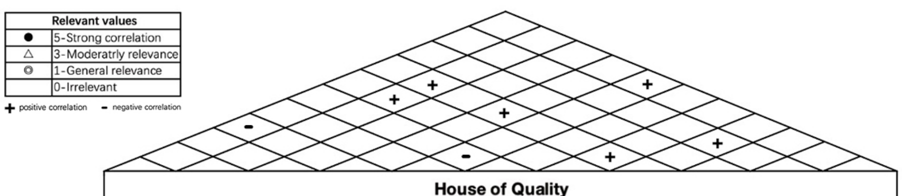
In this study, a complete House of Quality (HOQ) model was developed based on a previously identified set of 11 user requirements and technical features. To populate the relationship matrix, eight frequent users were randomly selected from each of the two parks (Sites A and B) and combined with twelve previously consulted experts to form a 20-member QFD evaluation panel. A collaborative scoring method was employed to evaluate the strength of association between each pair of user needs and technical features, resulting in the final HOQ relationship matrix. As illustrated in Fig. 6, within the HOQ structure, user requirements were located on the "left wall," their corresponding weights on the "right wall," and technical features were positioned across the "roof," forming an engineering-oriented response framework. Positive correlations were represented using a "+" symbol, and negative correlations with a "–," forming the roof of the matrix. The body of the matrix—the "room"—was filled based on the evaluated relevance between each user requirement and the corresponding technical features of the parent-child interactive seating. The strength of associations was represented by symbolic markers: "●" for strong relevance (5), "△" for moderate relevance (3), "◎" for weak relevance (1), and a blank cell for no relevance (0) (Maisano *et al.* 2024). The following formulas were applied to calculate both the relative and absolute importance weights,

$$w_i' = \frac{w_i}{\sum_{i=1}^{n} w_i'} \tag{11}$$

$$w_j = \sum_{i=1}^{n} w_i' \, R_{ij} \tag{12}$$

$$w_j' = \frac{w_j}{\sum_{j=1}^{n} w_j} \tag{13}$$

where w_i' represents the relative importance of user need, w_i, its absolute importance, R_{ij}, the correlation coefficient between user need i and technical feature, w_j, the absolute importance of technical feature, and w_j', its relative importance.



NO.	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	weight
M5	●		◎		◎				◎		◎	0.1756
M1	◎	●	△	◎			△	◎	●			0.1487
M7			●			△			◎			0.0904
M4	◎	△	△	●			◎	△	△			0.0819
M8	△				●	◎					△	0.0503
M2			◎			●			◎			0.0314
O6				◎			●	△		◎		0.0369
A3		●	△	△		◎	△	●	◎	△		0.0869
A6		△	△		◎	△			●		◎	0.0503
A1				◎			△	△		●		0.0389
A4	◎	△	△		△	◎	△		△		●	0.0339
Importance	1.2934	1.6763	1.8641	0.8947	0.5791	0.7502	1.1916	1.0563	1.7267	0.4921	0.5463	
Rank	4	3	1	7	9	8	5	6	2	11	10	

Fig. 6. HQD House of Quality for parent-child interactive seating

QFD Results Analysis

To further highlight the prioritization of technical elements in the design of parent-child interactive seating for children's parks, the technical features were categorized into three levels according to their composite importance scores as determined by the QFD analysis. Features with scores above 1.5 were classified as Level 1 (high importance), those between 1.0 and 1.5 as Level 2 (moderate importance), and those below 1.0 as Level 3 (low importance). Based on this classification, a structured categorization of technical attributes and functional modules relevant to the parent-child seating design in children's parks was established. As shown in Table 11, the overall functional deployment strategy for the seating systems was reviewed and refined by the research team.

Table 11. Technical Feature Ranking for Parent-Child Interaction

Level	Requirement Attribute	Design Element (Functional Attribute)	Importance Rank
Level 1	M	D3 Double-Layer Seating – Shared Backrest Ergonomic Structure	1
	A	D9 Standardized Modular Components	2
	M	D2 Block-Based Construction	3
Level 2	M	D1 Blurred Boundaries and Environmental Integration	4
	O	D7 Parent-Child Interaction Achievement Badge System	5
	A	D8 Cooperative Parent-Child Game Interaction	6
Level 3	M	D4 Dialogue-Oriented Layout	7
	M	D6 Multi-Sensory Safety Handrail System	8
	M	D5 Recycled HDPE and Regenerated Plastic-Composite Materials	9
	A	D11 Lightweight Movable Base Seat	10
	A	D10 Smart Writable Coating Panel	11

Level 1 Functional Analysis: At this level, the design of parent-child interactive seating in children's parks is required to comply primarily with the ergonomic standards outlined in ISO 26800 (International Organization for Standardization 2011). First, Double-Layer Seating – Shared Backrest Ergonomic Structure is regarded as a core design feature. This configuration allows for accommodation of varying body dimensions between adults and children through a tiered height system, thereby improving comfort and promoting interpersonal closeness. Second, the integration of standardized modular components facilitates functional adaptability and maintenance efficiency, while also complying with key principles of lifecycle management in sustainable design. This approach contributes to resource conservation and prolongation of product lifespan (Sonego *et al.* 2018). Finally, the adoption of block-based construction allows for the integration of playful interaction with structural design. Informed by Gibson's theory of affordances, this feature supports diverse spatial configurations that promote child-led exploration and parent-child collaboration, thereby enhancing both interaction quality and environmental engagement (Gibson 2014). Therefore, Level 1 functions collectively form the foundational framework of the parent-child interactive seating system by ensuring safety, comfort, and sustainability.

Level 2 Functional Analysis: At this level, the focus is directed toward enhancing visual integration and emotional engagement. First, the function of blurred boundaries and environmental integration is aligned with Christopher Alexander's concept of "boundary ambiguity," which emphasizes the role of semi-open and gradual transitions in enhancing spatial permeability and psychological affinity (Alexander 2017). Effective environmental integration is considered to enhance the visual continuity of the seating system and to support autonomous exploration by children, thereby contributing to the ecological coherence of the overall park environment. Second, the parent-child interaction achievement badge system, as a gamified design element, is intended to enhance cooperative experiences through task-based incentives and feedback mechanisms. This feature has been shown to increase usage frequency and reinforce user engagement. In addition, the cooperative parent-child game interaction—based on small-scale cooperative game scenarios—is designed to expand the functional scope of the seating system and to reflect foundational theories that link play with social and cognitive development. Therefore, Level 2 functions, as extensions of Level 1, are regarded as essential to fulfilling the holistic design objectives of parent-child interactive seating.

Level 3 Functional Analysis: At this level, the focus is directed toward the detailed optimization of parent-child interactive seating. Through the dialogue-oriented layout and multi-sensory safety handrail system, the design is intended to extend beyond basic functionality by enhancing communicative convenience between parents and children and supporting improved safety for child users. The use of recycled HDPE and regenerated plastic-composite materials is aligned with the ecological design principles outlined in ISO 14001 and is indicative of environmental responsibility in lifecycle management and low-carbon material adoption (Lewandowska and Matuszak-Flejszman 2014). A lightweight movable base seat is designed to improve the adaptability of the seating system to diverse site conditions, thereby allowing for flexible deployment in varied usage scenarios and enhancing spatial responsiveness. Moreover, the smart writable coating panel is implemented as a digital interactive feature, providing children with a platform for creative expression and autonomy. This function is consistent with the design principles of child-friendly environments, which emphasize autonomy and creative stimulation. Although Level 3 functions are positioned as supplementary within the user demand hierarchy, they serve a critical supportive role in enhancing the overall performance of parent-child interactive seating in children's parks.

RESULTS AND DISCUSSION

Research Findings

Design Scheme Generation

To efficiently translate user needs into implementable design solutions, a hybridized design workflow was developed through the integration of a Large Language Model (LLM) and a diffusion-based image generation model within the QFD analysis process. This approach was intended to enhance both the semantic fidelity and functional coverage of early-stage design outputs (Chen *et al.* 2024). The 11 key design attributes and their corresponding priority weights, as identified during the QFD phase, were employed as core semantic inputs. These were merged with a triadic semantic unit consisting of "functional attributes–usage scenarios–parent-child interaction behaviors" to generate design prompts. A set of visualized concept sketches for parent-child interactive seating was subsequently generated by the system.

Fig. 7. Dataset of parent–child interactive seating in children's parks

Fig. 8. Parent-child interactive seating for children's parks – Scheme 1

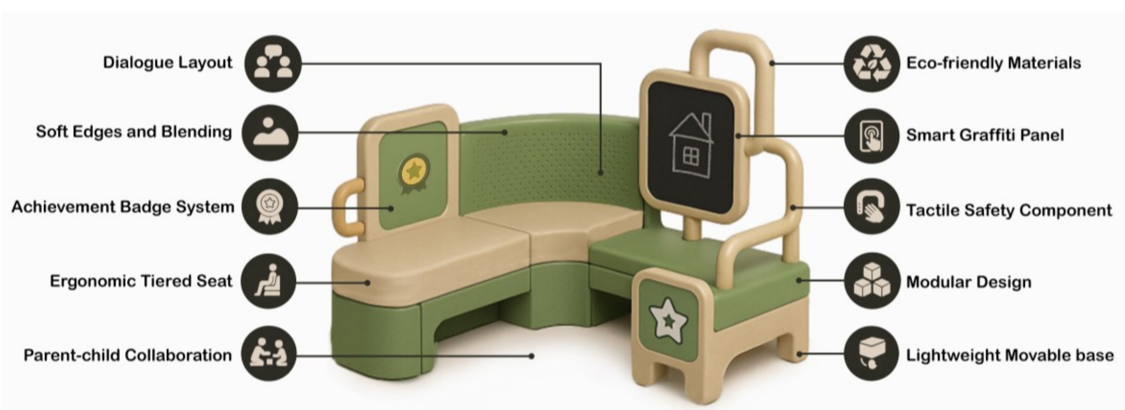


Fig. 9. Parent-child interactive seating for children's parks – Scheme 2

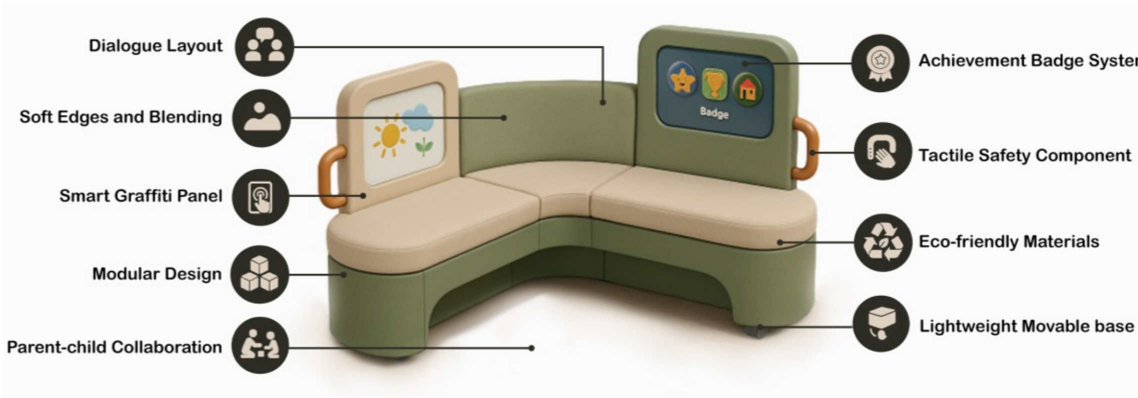


Fig. 10. Parent-child interactive seating for children's parks – Scheme 3

Through continuous iteration, multiple candidate prototypes were produced, resulting in a preliminary dataset of design options (Fig. 7). From this dataset, three high-matching schemes were selected based on criteria such as functional coverage, semantic alignment, and design completeness. These three proposals were further refined along three distinct pathways—structural adaptability, interactive playability, and emotional stimulation—which represent the core design outputs of this study.

Scheme 1: The scheme is centered on "Structural Guidance and Parent-Child Collaboration" and is designed to facilitate family co-creation through modular connections and interactive components. As shown in Fig. 8, a standardized modular framework is combined with a lightweight base to form a reconfigurable and movable platform composed of functional units. An L-shaped dialogic layout is adopted to support a face-to-face spatial configuration that enables parent-child interaction. Recyclable HDPE and bamboo–plastic composite materials are employed as primary structural materials, aiming to minimize environmental impact while ensuring structural stability. A smart drawing panel is embedded in the backrest, and an interactive game table is centrally positioned to promote collaborative construction activities and problem-solving dialogue between parents and children. Overall, the scheme is considered suitable for open park environments characterized by high structural flexibility and interactive demand.

Scheme 2: Building upon the concept of "Embedded Multi-Functional Interaction," this scheme is intended to support multi-role collaboration and the expansion of interactive play functions. As illustrated in Fig. 9, a dual-height structure is incorporated into the seating system to facilitate simultaneous eye-level and physical interaction between parents and children, thereby promoting shared use across age groups. A parent-child cooperative game unit and an intelligent drawing panel system are integrated into the design. The former is designed to stimulate children's exploratory behaviors through micro-scale cooperative play, while the latter is configured to offer interactive visual feedback, thereby creating a closed-loop mechanism between task scenarios and user responses. A modular assembly structure is adopted for the system, with all components designed according to a unified interface standard to ensure ease of deployment and maintenance. Material selection is based on the continued use of recycled plastics and bamboo–plastic composites, combined with a lightweight base and tactile safety elements to ensure a robust and safe experience suitable for parent-child users across age groups.

Scheme 3: This scheme is centered on "Ecological Integration and Immersive Experience" and is designed to stimulate children's creative behavior and emotional engagement through naturalistic forms and multifunctional visual components. As illustrated in Fig. 10, a curved, enclosed layout is adopted to reflect natural ecological flows, thereby enhancing spatial cohesion and interactive dynamics. An intelligent drawing panel is positioned at the end of the left-side seat, while a “Parent-Child Badge Unlocking” system is embedded in the backrest of the right-side seat. This feature enables users to unlock virtual achievement badges by completing designated collaborative tasks, thereby functioning as both a behavioral recording mechanism and an incentive for emotional bonding—enhancing the immersive experience. A pulley system is integrated beneath the seat to support flexible repositioning across multiple usage scenarios. Overall, the system emphasizes a feedback mechanism of “emotional response–visual recognition–social motivation,” thereby providing a refined response to the emotional dimensions of parent-child interaction.

In summary, the three proposed schemes represent distinct design trajectories grounded in spatial adaptability, emotional engagement, and interactive play behavior, illustrating the system’s ability to respond to diverse user needs. All schemes were subjected to semantic filtering, structural evaluation, and iterative refinement by the research team based on the generated prototype database, ensuring close alignment with functional prioritization, implementation feasibility, and sustainability. This generation–filtering workflow has demonstrated the synergistic potential of large language models and generative image tools for user-oriented public facility design. It provides a novel technical pathway and methodological framework for the development of urban micro-scale public facility prototypes.

Scheme evaluation

The Fuzzy Comprehensive Evaluation (FCE) method, a classical technique for addressing multi-criteria decision-making under uncertainty, is used to transform expert- or user-based fuzzy linguistic assessments into comparable quantitative vectors through the incorporation of weight vectors within the membership space. This approach is considered effective in preserving information integrity while alleviating the “threshold discontinuity” issue commonly observed in traditional linear weighting methods (Chen *et al.* 2024). FCE has been extensively applied to the screening of complex product concepts and the evaluation of optimal design alternatives, and it is recognized for its strong reliability and discriminative capability owing to its integration of qualitative and quantitative decision-making dimensions (Yang *et al.* 2021).

In this study, the Fuzzy Comprehensive Evaluation (FCE) method was applied to evaluate the overall performance of three parent-child interactive seating prototypes. A panel consisting of ten interdisciplinary experts and five parent-child users with practical usage experience was invited to participate in the evaluation process. The assessment was conducted using eleven core design attributes identified during the QFD phase, so that the outcomes generated by the integrated GT–KANO–AHP–QFD model could be validated in terms of scientific rigor and practical relevance.

The specific evaluation procedure is outlined as follows:

1. Construction of the Evaluation Indicator Set. Based on the eleven core design elements identified through the QFD output, a fuzzy evaluation indicator factor set m was developed and expressed as follows: $m_1 = \{d_1, d_2, ..., d_{11}\}$ = { double-layer seating – shared backrest ergonomic structure, standardized modular components, block-based construction, blurred boundaries and environmental integration, parent-child interaction achievement badge system, cooperative parent-child game interaction, dialogue-oriented layout, multi-sensory safety handrail system, recycled HDPE and regenerated plastic-

composite materials, lightweight movable base seat, smart writable coating panel }.

2. Determination of Evaluation Grades and Scoring Criteria. An evaluation set X was defined as X = {X_1, X_2, X_3, X_4} = {Excellent, Good, Fair, Poor}, with each grade being assigned a corresponding numerical score. In accordance with expert consensus, score intervals were specified for each evaluation grade as follows: “Excellent” was defined as 90 and above; “Good” as 80–89; “Fair” as 60–79; and “Poor” as below 60. Each grade may be assigned an appropriate fuzzy weight to facilitate subsequent computations.

3. Construction of the Fuzzy Comprehensive Evaluation Matrix. Each of the three design schemes was evaluated by the expert panel, and a fuzzy evaluation matrix R was subsequently constructed to correspond with the indicator set m. The fuzzy comprehensive evaluation matrix is defined as a composition of membership degrees, indicating the relationship between each evaluation indicator and the evaluation grade set, as shown in Eq. 14).

$$R = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1n} \\ s_{21} & s_{22} & \cdots & s_{2n} \\ \vdots & \vdots & & \vdots \\ s_{n1} & s_{n2} & \cdots & s_{mn} \end{bmatrix} (0 \leqslant S_{ij} \leqslant 1) \quad (14)$$

4. Calculation of the Weighted Comprehensive Evaluation Vector. To ensure effective integration of the evaluation results with the indicator weights, a weighted average fuzzy aggregation model was employed. The element weight vector obtained from the QFD phase, $W = (w_1, w_2, ..., w_m)$, was integrated with the corresponding fuzzy evaluation matrix R through mathematical synthesis to produce the final comprehensive evaluation vector P, which reflects the overall degree of membership of the scheme across each evaluation grade. See Eq. 15).

$$P = WR^R = (w_1, w_2, \cdots, w_m) \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1n} \\ s_{21} & s_{22} & \cdots & s_{2n} \\ \vdots & \vdots & & \vdots \\ s_{n1} & s_{n2} & \cdots & s_{mn} \end{bmatrix}^R \quad (15)$$

5. Calculation of Final Scores and Scheme Ranking. To facilitate the ranking of the three design schemes, a satisfaction scoring function was introduced to transform fuzzy vectors into real-valued outputs. A linear satisfaction mapping function was applied to assign numeric weights to the four evaluation levels, specifically: Excellent = 1.0, Good = 0.8, Fair = 0.6, and Poor = 0.4. This weighting approach has been widely used in domains such as product design, educational evaluation, and service satisfaction analysis, as it effectively captures cognitive differences and ranking sensitivity across evaluation levels while maintaining computational simplicity. The aforementioned matrix operations and satisfaction scoring functions were performed for each of the three schemes, and the final comprehensive scores were subsequently derived (Table 12).

Table 12. FCE Evaluation Results for Parent-Child Interactive Seating

Scheme	membership degree				Composite Score
	Excellent	Good	Pass	Fail	
Scheme 1	0.3057	0.3286	0.2363	0.1294	0.762
Scheme 2	0.4548	0.3347	0.1673	0.0431	0.840
Scheme 3	0.3687	0.3175	0.2551	0.0586	0.799

As shown in Table 12, Scheme 2 was found to have the highest overall score, with a value of 0.840, indicating outstanding overall balance. It performed particularly well in key dimensions such as functional adaptability, structural safety, and emotional interactivity, and was highly rated by both experts and users. Scheme 3 ranked second, with a score of 0.799. It demonstrated clear strengths in spatial flexibility and collaborative interaction, rendering it suitable for diverse public space applications. By comparison, Scheme 1 obtained an overall score of 0.762. Although some advantages were observed in emotional experience and interactive mechanisms, it exhibited relative weaknesses in lifecycle adaptability and structural stability, which constrained its overall performance in the evaluation.

Research Discussion

Systematic capture of the user voice: A closed-loop path from multisource qualitative insights to quantitative validation

A closed-loop demand acquisition process was developed in this study, transitioning from qualitative exploration to quantitative validation. The process consisted of four sequential stages: expert workshops, semi-structured interviews, grounded theory coding, and bidirectional Kano questionnaires. Through the integration of multiple data sources and analytical pathways, a structured transformation was enabled from users' subjective perceptions to formalized design requirements. This approach not only reduced the risks associated with methodological singularity—such as limited perspectives and sampling bias—but also facilitated the continuous accumulation and systematic synthesis of user-centered data, beginning with perceptual insights and progressing toward structured generalizations.

During the qualitative analysis phase, key scenarios and an initial variable framework were initially identified through a series of expert workshops. Subsequently, semi-structured interviews were conducted to systematically capture behavioral representations and perceptual feedback from both parent and child users during real-world interactions. By applying the constant comparative method of grounded theory, an operationalizable semantic map of user needs was derived from the raw data, thereby deepening the understanding of differentiated behavioral patterns among multiple stakeholders within the context of co-present parent-child interactions. In the quantitative validation phase, a bidirectional Kano questionnaire was employed to address the issue of information asymmetry resulting from children's limited expressive abilities and parental perceptual biases. This approach independently captured the satisfaction–functionality mapping for both children and parents, thereby improving the accuracy and age-appropriateness of hierarchical demand classification.

Compared to conventional approaches that rely solely on questionnaires or focus groups, a multi-method cross-validation strategy was adopted in this study to enhance the credibility, external validity, and reproducibility of the findings. This strategy is consistent with Denzin's four-dimensional triangulation framework, which encompasses data, investigators, theory, and methodology (Denzin 2012). In current practices of parent–child facility design, surveys are often concentrated on adult perspectives or single-point feedback. In contrast, the closed-loop pathway constructed in this study places greater emphasis on dynamic feedback, bidirectional alignment, and cross-age perceptual co-construction, thereby addressing critical gaps in practice—namely, the lack of multi-actor behavioral modeling and the insufficient direct participation of children. Within the domain of inclusive design, this approach addresses a significant gap related to the limited consideration of children's subjective experiences. It provides a structured and traceable foundation for subsequent behavioral modeling and product prototyping.

Integrated innovative research methodology: An end-to-end chain-coupled framework based on GT–Kano–AHP–QFD

A chain-coupled methodological framework was established in this study, integrating Grounded Theory (GT), the Kano model, the Analytic Hierarchy Process (AHP), and Quality Function Deployment (QFD). Four stages of user research were systematically delineated, including demand discovery, attribute classification, weight quantification, and technical translation. In doing so, a logically coherent, end-to-end process was formed, linking user needs to technical implementation.

Although prior studies have combined the Kano model, AHP, and QFD in product design—for instance, Kano and QFD were integrated by Shen *et al.* (Shen *et al.* 2000) to optimize user-oriented product features—most of these applications have remained confined to a linear "standard weight–function mapping" framework and have lacked substantive engagement with early-stage qualitative insights. Although Neira Rodado *et al.* (2020) introduced DEMATEL to strengthen the analysis of inter-factor relationships, the lack of qualitative grounding during early phases has remained insufficiently addressed. Building upon this foundation, grounded theory was incorporated at the front end of the methodological chain, thereby enhancing the capacity to model the generative mechanisms of original user needs. This integration was found to enhance the model's potential for micro-level semantic recognition and behavioral adaptation.

Compared with existing public seating design processes, the most distinctive feature of the proposed model lies in its closed-loop capability to transform across "behavioral semantics–demand structures–technical functions." In practice, public facilities are often designed based on standardized templates, which lack customized decision-making grounded in the heterogeneity of user needs. By adopting a nested integration approach, the proposed model achieves stepwise reconstruction and precise translation of user perceptions at the micro level, thereby offering more flexible decision-making logic tailored to the highly diverse urban use scenarios.

This coupling logic of "front-end qualitative, mid-stage quantitative, and back-end technical mapping" was found to enhance the depth of demand interpretation and to provide a robust semantic foundation for the structured integration of generative AI systems. The synergistic potential between deeply embedded user need semantics and data-driven design tools was thereby demonstrated, offering a sustainable paradigm for multi-objective public facility design.

Sustainability-oriented behavioral drivers: Gamification and sustainable development

The three parent-child interactive seating prototypes were systematically evaluated through the Fuzzy Comprehensive Evaluation (FCE) method. The results revealed that each prototype attained an overall membership level exceeding the "Good" threshold. Scheme 2 was found to yield the highest score, suggesting that its integration of dual-height seating, cooperative play, and emotional badge mechanisms provided the most effective balance between parental and child needs.

From a behavioral mechanism perspective, the "achievement badge system" and "cooperative gameplay" are regarded as gamification design elements. A substantial body of empirical research has confirmed that gamification mechanisms—such as badges, point systems, and leaderboards—are effective in enhancing user engagement and emotional attachment in both educational and public domains (Ouariachi *et al.* 2020). In terms of sustainability, a high level of acceptance was reported by users toward the use of recycled HDPE and bamboo–plastic composite materials. These materials were recognized for their mechanical strength, environmental durability, and eco-friendly attributes, and were positively rated in terms of their "perceived environmental visibility." Moreover, their adoption has been found to align closely with the broader trend of green transformation in urban public infrastructure.

Compared with traditional design approaches, previous parent–child seating solutions have primarily focused on meeting basic requirements of structural dimensions and functional configurations, with limited attention to coupling material sustainability with the optimization of interaction mechanisms during the early design stages. Building on behavior-driven logic, this study proposes a three-layer collaborative model of "material perception–behavioral feedback–emotional motivation," which provides a practical pathway for advancing urban public facilities toward a coordinated evolution of cognition, emotion, and ecology. Overall, the acceptance of public design has been shown to be influenced by both the perceived interactivity of engagement mechanisms and the perceptibility of sustainable features. This finding provides a strategic basis for the integrated optimization of behavioral mechanisms and material perception in the inclusive design of public facilities targeted at parent–child users.

Key Research Findings

This study constructed a four-stage chain-coupling pathway of "requirement elicitation–requirement classification–weight quantification–technical translation," centered on the GT–Kano–AHP–QFD framework. This approach effectively established a closed-loop process for transforming user needs from qualitative understanding to quantitative decision-making, thereby advancing the application of systematic user modeling in the design of parent–child public facilities. Compared with conventional approaches that rely on designer experience or single-questionnaire data, this study employed a multi-stage, multi-stakeholder, and data-driven mechanism that accommodates both the variability of children's expressions and the perceptual biases of parents, while also integrating environmental sustainability into the translation of user needs. As a result, the design elements and evaluation mechanisms achieved synchronous evolution in terms of interactivity and green value.

Theoretical and Practical Contributions

This study has systematically expanded user-centered design methodologies for public facilities at both the theoretical and practical levels. On the theoretical front, grounded theory analysis was strategically embedded at the outset of the traditional "Kano–AHP–QFD" sequence, introducing a tripartite coupling paradigm involving "front-end qualitative analysis, mid-stage quantification, and back-end translation." This approach has addressed a critical gap in early-stage semantic modeling by enhancing both contextual sensitivity and semantic completeness in the modeling of user needs. Moreover, this study was one of the first to incorporate both emotional motivation and ecological sustainability as dual dimensions into the QFD "House of Quality" framework, thereby extending the theoretical applicability of QFD in emotion–environment co-optimization contexts. In addition, the Fuzzy Comprehensive Evaluation (FCE) method was employed to effectively address uncertainty in multi-objective decision-making, establishing a robust evaluation paradigm specifically suited for micro-scale public facilities. On the practical level, a "structure–interaction–emotion" trinity design strategy was proposed to offer a systematic framework for the development and retrofitting of urban parent–child seating, reinforcing their public engagement and educational value. The integration of large language models and diffusion-based image generation models into the design workflow has further demonstrated the potential of AI in facilitating rapid, cost-efficient design iteration during early concept stages. Finally, a traceable data chain established from user needs to technical translation was shown to provide quantitative support for cross-sectoral coordination among policy makers, product developers, and infrastructure operators. This mechanism has significantly enhanced the precision and transparency of public resource allocation.

Research Limitations and Future Work

Despite the positive progress achieved in methodological construction and empirical application, several limitations remain that warrant further attention. First, with respect to regional representativeness, the current investigation was confined to specific cities and population groups, resulting in a relatively homogeneous cultural background. This limitation restricts the external validity of the study's findings. Future research should undertake cross-validation within children's park settings across diverse cultural contexts to evaluate the generalizability and adaptability of the proposed integrated innovation model. Second, due to ethical review requirements and the limited expressive capabilities of children, parental proxy responses were employed to ensure the authenticity and validity of the data. These responses reflected parents' integrated observations and interpretations of their children's behavioral tendencies and preferences. While this indirect method partially compensates for children's inability to articulate needs directly, it may limit the precise identification of implicit or latent demands. Subsequent studies are encouraged to incorporate more age-appropriate behavioral sensing methods—such as gamified observation techniques, wearable sensors, or computer vision recognition tools—to capture children's natural behavioral trajectories and offer deeper insights into age-specific heterogeneity in interaction and emotional feedback. Third, the evaluation of the proposed prototype was primarily conducted through short-term usage scenarios and simulated environments, lacking long-term deployment data under real-world conditions. Key aspects such as material durability, maintenance convenience, and life-cycle costs have yet to be validated. Especially under high-frequency and multi-period usage in public settings, the long-term structural stability, anti-aging performance, and safety of the product over an extended operational lifespan require further empirical verification. Future efforts will incorporate field experiments and multi-round dynamic assessments from a life-cycle perspective. Finally, although this study focused on children's parks as the primary application scenario, the proposed methodological framework and design strategies hold considerable potential for extension to other types of public spaces. Further exploration may assess the model's applicability across a variety of settings, including campus outdoor areas, preschool institutions, parent–child interaction clubs, and healthcare or rehabilitation environments. Through scenario transfer and functional adaptation, the generalizability and differentiated customization strategies of the model can be critically evaluated.

In summary, with the rapid advancement of artificial intelligence and digital twin technologies, future research is encouraged to develop a closed-loop system that integrates real-time sensing, data-driven insights, and intelligent generation. Such a framework would enable adaptive design and progressive optimization of public facilities through multi-stakeholder participation, thereby providing intelligent infrastructural support for the continuous evolution of more inclusive, resilient, and sustainable urban environments.

CONCLUSIONS

1. This study established a chain-coupled methodological framework based on GT–Kano–AHP–QFD, encompassing four sequential stages: demand identification, demand classification, weight quantification, and technical translation. This integrated framework effectively bridged qualitative understanding and quantitative decision-making in user research, thereby advancing the application of systematic user modeling in the design of parent–child public facilities.
2. Expert workshops and semi-structured interviews were conducted to collect multidimensional behavioral and perceptual data from users of parent–child seating in real-world settings. Through open coding grounded in grounded theory, a practical semantic demand map was derived, establishing a solid foundation for subsequent structured modeling.
3. Bidirectional Kano questionnaires were utilized to independently capture satisfaction–functionality mappings from both child and parent perspectives, thereby refining the classification of four core functional attributes and mitigating potential bias stemming from intergroup information asymmetry.
4. The Analytic Hierarchy Process (AHP) was implemented to determine the relative weights of the identified attributes, which were subsequently translated into technical modules through the QFD methodology. A hierarchical technical demand mapping model was thereby established.
5. Building on this model, an AI-assisted workflow was established through the integration of a large language model (LLM) and a diffusion-based image generation model. This hybrid design framework enabled the iterative generation of three parent–child seating prototypes.
6. Finally, a Fuzzy Comprehensive Evaluation (FCE) was carried out to assess the prototypes, thereby identifying the optimal solution that most effectively balanced functionality, interactivity, and material sustainability.

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