Research on the Design of Growable Children’s Beds Based on Combined Hierarchical Analyses

Nan Wang and Yin Zhao *

Although the market share of domestic children’s furniture is increasing annually, some potential problems limit its long-term and stable development, and there is still a gap in China compared with foreign countries. This study focused on the demand preferences for growable children’s beds and examined the design features that influence these preferences. This study introduces a combination of Hierarchical Analyses (AHP), Quality Function Development (QFD), and the Platts Conceptual Decision Matrix (PUGH) into the innovative design of a research model for children’s furniture (AHP-QFD-PUGH). This study screened and classified the decision-making indicators obtained from the research, ranked their importance by quantitative calculation, and finally proposed an optimal design solution. Additionally, to further study the structural characteristics, the function-behavior-structure (FBS) model served as a supplementary analysis tool to effectively circumvent subjective factors in product design. This integrated model accurately explored user needs and product characteristics, providing substantial guidance and new ideas for optimizing the design of growable children’s beds and enhancing growth of the children's furniture industry.

DOI: 10.15376/biores.19.4.8084-8102

Keywords: Growable children's beds; AHP; QFD; PUGH decision matrix; FBS model; Product characteristics

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

INTRODUCTION

With economic development and changes in family structure, the market share of children’s products continues to rise, and the children’s furniture market faces new opportunities. According to 2021 data, the number of children under 16 years old in China exceeded 300 million (Han *et al.* 2021). The retail sales of children’s furniture are approximately 100 billion yuan. Approximately 40% of Chinese children have their own room and furniture (Luo *et al.* 2023), which shows that children’s furniture demand is experiencing explosive growth. In addition to several common children’s beds on the market, including cribs, cradle beds, single beds, bunk beds, and functional beds (Zhang and Xu 2020), children's beds, as an important part of children’s furniture, are being constantly subdivided according to the needs of scenarios (Xia 2022), and demands for designs have also begun to diversify. Research shows that some foreign children’s furniture has attracted much attention and is rapidly developing in the direction of environmental protection and safety, differentiation, multifunctionality, and creativity. For example, IKEA considers children’s ergonomics, styling, and color schemes and introduces a variety of multipurpose reusable household products for children (Ye *et al.* 2021b). The size of the bedroom furniture market for children (Fan and Zhao 2011), which is now becoming the most promising market in the U.S. furniture industry, is still growing. The traditional Italian crib can be combined and expanded into other furniture for children. Constrained by costs and investments, China's furniture industry struggles with weak original design and innovation (Li and Yao 2021), leading to single-use products, homogeneity, and a shortage of prominent independent design brands (Jiang and Chen 2023). Research has shown that children have a strong desire to explore and are rich in creativity. They enjoy interactive activities and like to explore the world around them actively. Meanwhile, they gradually have a wide range of interests and possess their own favorite objects and toys. They can arrange their own small space and have a certain degree of independence (Sun *et al.* 2024). However, many domestic children's furniture enterprises currently lack a deep understanding of the market; most children's beds are only 'miniaturized' adult furniture (Liu and Zhu 2023), emphasizing bright colors and cartoon patterns (Wang 2022; Ren and Zhu 2024) over structure and safety, and neglecting sustainable use, entertainment, and educational qualities (Yu 2010). In addition, children's furniture on sale in China generally has high prices and a short service life, resulting in many consumers preferring to place their children in adult beds, which is not only harmful to the development of children's bone structure but also leads to potentially fatal dangers (Nakamura *et al.* 1999). Moreover, although the design of domestic children's furniture is increasingly focused on eco-friendly materials (Wan *et al.* 2015), and even most consumers are willing to pay a price premium (Wan *et al.* 2018), the enforcement of environmental standards remains insufficient (Wei and Madina 2022). Domestic children's beds still have much room for development in terms of functionality, sustainability, safety, and fun (Mai *et al.* 2022). Many scholars have also proposed their own design suggestions. For example, a scholar designed a multifunctional modular children's bed through a comparative analysis of the characteristics of children's behavior and psychology at various stages, based on the principles of children's furniture design and the concept of growth. The study provided a new type of design idea better adapted to the growth of Chinese children (Huang and Wang 2020). With the help of the vision in product (VIP) design principle and analogical analysis method, future intelligent children's beds should have the interaction characteristics of comfort, exploration, and empathy with users (Tong 2023). The problems of non-standardized shape parameters and imperfect functional design of children's beds for two-child families were analyzed, and the KANO model and TRIZ theory were integrated into designing a multifunctional children's bunk bed (Zhu 2022). Although there is some scholarly research on children's beds, the research remains in a single theoretical category and lacks the application of comprehensive methods. The summary of the design indices of children's beds is also imperfect, not in-depth and has some limitations.

The Analytic Hierarchy Process (AHP) is a qualitative–quantitative demand-weighting research method used to help decision-makers make systematic analyses and judgments in complex decision-making environments (Huang *et al.* 2022). The method stratifies the decision factors for qualitative and quantitative analysis and ranks the results to improve decision-making efficiency and accuracy (Han *et al.* 2023). Quality Function Deployment (QFD) is a model that transforms user needs into product technical characteristics by establishing the House of Quality (HOQ) (Tian *et al.* 2024), aiming to transform customer needs into product or service design requirements so that the product or service can meet customer expectations (Xiong *et al.* 2023).

The Platts Conceptual Decision Matrix (PUGH decision matrix) is a quantitative decision analysis tool proposed by the British management scientist Stuart Pugh. It is used to qualitatively rank candidate solutions by comparing their scores with those of reference solutions; the tool is suitable for the efficient and systematic evaluation of designs at the evaluation decision stage (Li *et al.* 2021). The advantages of the comprehensive theoretical model include that it can be more objective in obtaining reliable experimental results. Using the AHP method for quantitative research and for quantitatively evaluating the priority of user requirements at the same time helps overcome the subjectivity of the affinity diagram (also known as the KJ method), thus improving the accuracy of user requirements research (Neira-Rodado *et al.* 2020; Wei *et al.* 2023). QFD can link user requirements with product functional characteristics and technical features to improve product and service quality at the product and service manufacturing phase (Ginting *et al.* 2020), which can compensate for the inability of AHP to directly translate user requirements into product functions (Li *et al.* 2023). The use of PUGH for solution evaluation decision-making helps rationalize and logically make decisions by validating the product's suitability through the ranking of design metric scores. Thus, in recent years, AHP and QFD have been widely applied in the field of furniture design (Jiao and Zuo 2021; Xu and Xia 2023; Wu *et al.* 2023) and they can help effectively capture and analyze the suggestions of customers and experts and improve the design and comprehensive planning of furniture. For example, AHP is used in the evaluation and design of dining chairs, which can shorten the time and cost of the design and greatly improve the quality of the chair as well as customer satisfaction (Liu *et al.* 2023). The AHP method has been used to conduct in-depth quantitative research on the design preferences of children's furniture from the characteristic elements of children's lockers (Zhao and Xu 2023; Zhang and Xu 2023), children's study tables (Miao *et al.* 2024), and other children's furniture (Miao *et al.* 2023). In addition, the QFD is utilized to determine the design preferences of users under the open office mode, providing new ideas for the design of office wooden tables (Lyu *et al.* 2022). Recently there have been many studies on the combination of AHP, QFD (Kwong and Bai 2002; Wu and Zhang 2022; Li *et al.* 2023), and PUGH applied to the field of product design, forming a complete product development process, and jointly improving the reliability and scientific nature of the design process. The three integrated models are mainly used in intelligent products (Zhu *et al.* 2022; Nixon *et al.* 2013), but not in the field of furniture design.

This study uses AHP, QFD, and PUGH decision-making (AHP-QFD-PUGH integrated model) to transfer user needs to product function and styling design and, ultimately, proposes an optimal design solution. Moreover, the function-behavior-structure (FBS) model can translate key design elements into specific structural design requirements (Cui 2024). Thus, to ensure the rationality of the design results, this study innovatively adds the FBS model based on AHP-QFD (Hu and Wang 2021) to achieve more accurate mapping between the final presentation of the product and key user needs (Zhang *et al.* 2023). The combination of these methods can provide scientific guidance for the innovative design of children's beds, as well as a new way of thinking about furniture design.

In summary, the purpose of this study is to provide new methods and ideas for the design and research of children's beds and similar furniture to promote children's bed design and development. The design preference characteristics of relevant users for children's beds are explored in detail, and substantial guiding suggestions are provided for optimizing the design of children's beds and enhancing children's growth-oriented furniture.

EXPERIMENTAL

Research Methodology

This study applied the AHP-QFD-PUGH integrated model to the design process of growable children's beds, which was divided into five steps: User requirement extraction, requirement hierarchy, requirement function transformation, function-behavior-structure mapping transformation, and design practice and evaluation. The design process of growable children's beds based on AHP-QFD-PUGH modeling is shown in Fig. 1. First, the KJ method was used to construct a list of user requirements for growable children's beds to accurately identify user requirements and extract functions. Second, the AHP method was used to assign weights to the evaluation indicators to improve the scientific nature of the program evaluation process. Third, the QFD method was used to rank the importance of the design features that match the corresponding requirements. Fourth, the FBS model was used to achieve hierarchical mapping of function-behavior structures, thus transforming the design features derived from the QFD model into structural features to improve the feasibility and reliability of user behavior and structural design (Xuan *et al.* 2021). Finally, design practice was carried out based on the above analyses. The PUGH decision matrix was constructed to validate and evaluate the multiple schemes, and the optimal scheme was eventually selected.

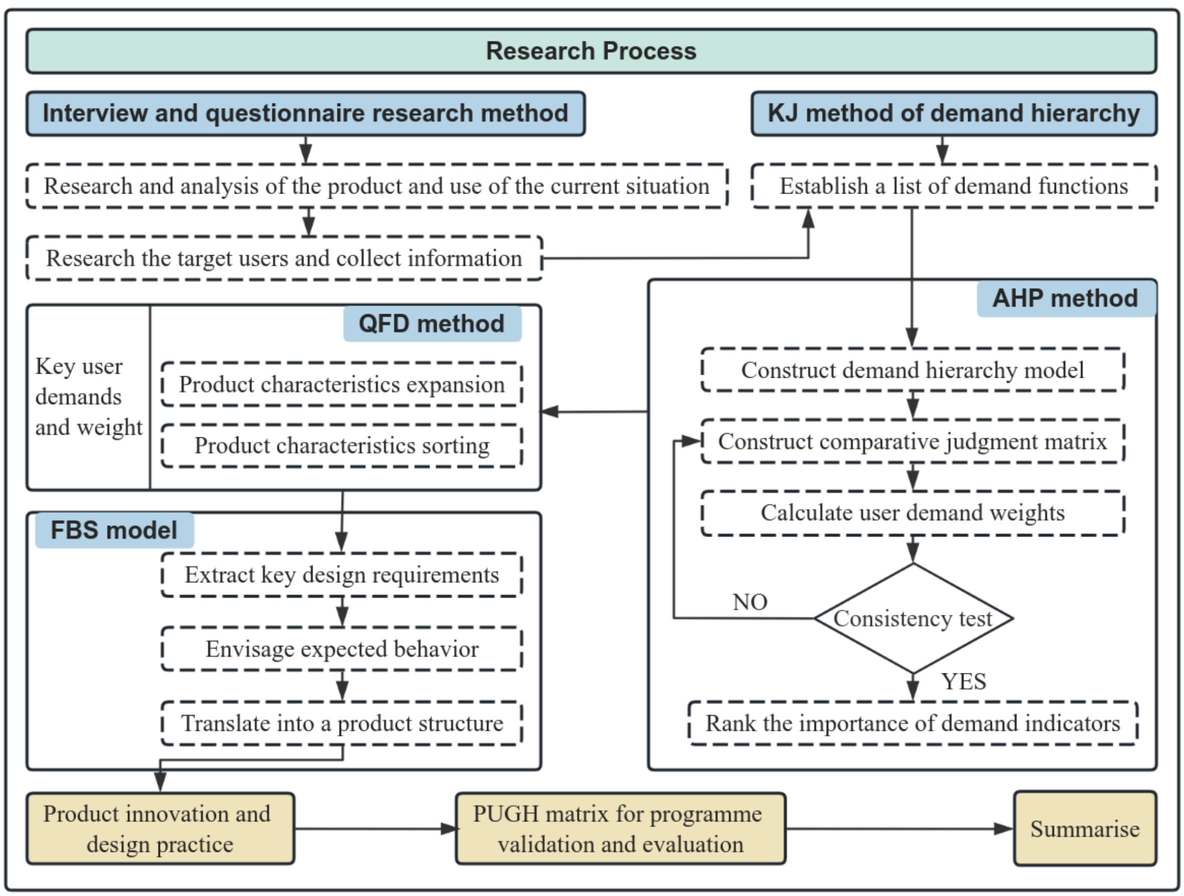

Fig. 1. Flow chart of growable children's beds based on AHP-QFD-PUGH modeling

Research Process

Acquisition of growing child beds design requirements

First, a research questionnaire was designed using a large amount of data and performing literature searches on children's furniture and beds. After that, the basic needs were researched *via* interviews and questionnaires, and the third-level demand indicators among the indicators of growable children's beds were filtered. The survey included children aged 6 to 12, parents ranging from 25 to 45 years, and relevant designers. A total of 73 questionnaires were distributed in this survey. There were 4 invalid questionnaires that were removed, leaving a total of 69 valid questionnaires, with an effective acceptance of 94.5%. On this basis, the scattered and disorderly demand indicators were categorized and upwardly refined and summarized into four types of second-level demand indicators: appearance, system, function, and economy. The appearance demands included a beautiful shape, warm colors, and no corners to prevent bumping. The systemic demands included a stable structure with a robust load-bearing capacity, an adjustable size, a scientific structure, and easy assembly. The functional demands included storage, parent-child interaction, growth ability, fun design, ease of cleaning and safety protection. The economic demands included cost-effectiveness, environmental sustainability, and durability. Eventually, the first-level demand indicator for the product design of growable children's beds was derived. These demands were more in line with the results of existing research on the demand for children's beds (Yan 2023; Liu and Wang 2024).

AHP method to determine the weight of each indicator

After obtaining the ordered and comprehensive user demand indicators, the hierarchical analysis method was used to conduct quantitative research on the indicators collected by collation. Hierarchical analysis, as a decision-making method that combines qualitative and quantitative analysis, can compensate for the possible problems of strong subjectivity and difficult operation, thereby improving the objectivity and effectiveness of subsequent decision-making.

First, based on the list of user requirements obtained from the KJ method above, the elements were divided into three layers: the target, criterion, and solution. The target layer was the design of growable children's bed products, which was indicated by the letter Y. The four secondary demand indicators were designated as the criterion layer and were denoted by the letters N_1, N_2, N_3, and N_4. The criterion layer was used to expand the detailed division of 16 solution layers, denoted by the number N_{ij} (i = 1,2,3,4; j = 1,2..., m), to construct the hierarchical structure model, as shown in Fig. 2. Second, the study designed the AHP scoring table and invited 5 parents with extensive experience in purchasing children's furniture, 3 scholars in related fields, 4 furniture designers, and 3 furniture salespeople, totaling 15 people, to form a decision-making team. A nine-point scale was used for comparing importance, to assign values to the needs of each of the criterion layers and the solution layer. The judgment matrix scale is defined in Table 1. Third, the AHP scoring table data were analyzed to calculate the eigenvectors and weights of each requirement. A consistency test was also performed on the judgment matrix to avoid arbitrary scoring by experts, resulting in contradictory ratings. Finally, the weight of each program layer was multiplied by the weight of the corresponding guideline layer to calculate the comprehensive index value of each level of elements overall. Furthermore, combined with the above expert team's opinion, each specific demand was sorted to obtain user demand priorities to provide decision support for the subsequent development and design of the growable children's bed. The consistency index (CI) and consistency ratio (CR) are defined by Eqs. 1 and 2, respectively,

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (1)$$

where λ_{max} is the largest eigenvalue of the judgment matrix, and n is the order of the judgment matrix. Equation 2 is as follows,

$$CR = \frac{CI}{RI} \quad (2)$$

where the inconsistency of the data in the judgment matrix is within the permissible range and its consistency is considered acceptable when CR < 0.10, otherwise the judgment matrix should be appropriately corrected.

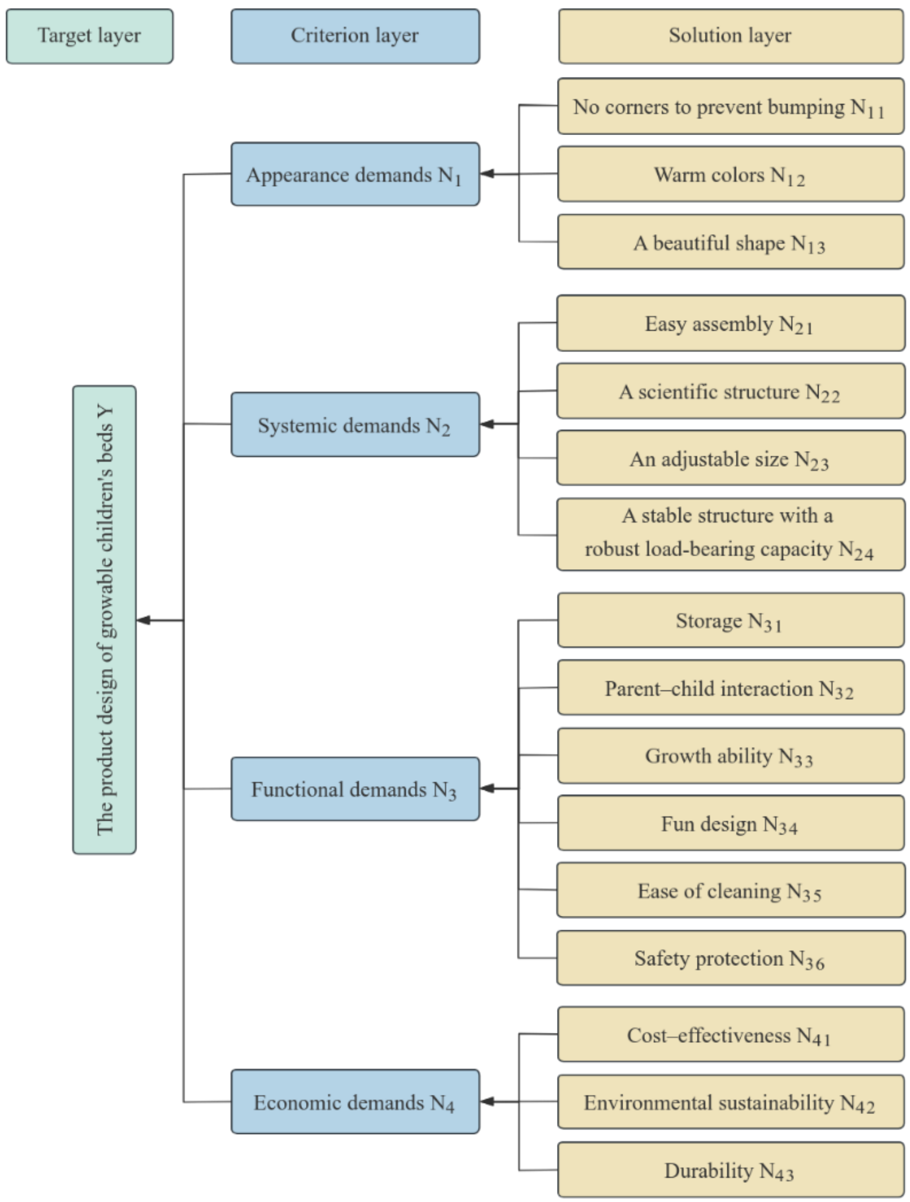

Fig. 2. Hierarchical structure model of growable children's beds

Table 1. AHP Scoring Table

Scale	Level of Importance
1	N_i, N_j elements are equally important
3	N_i is slightly more important than N_j
5	N_i is significantly more important than N_j
7	N_i is obviously more important than N_j
9	N_i is definitely more important than N_j
2，4，6，8	Intermediate values of the above adjacent judgments
Inverse of scale	If the ratio of the importance of element N_i to element N_j is n, then the ratio of the importance of element N_j to element N_i is 1/n

Analysis of the AHP model results

The mathematical method of geometric mean was used to process the statistical results of the 15 AHP research questionnaires completed by the decision-making team to form a comprehensive assignment result (Qiu and Zu 2018), and then the formula was used to calculate the single-level weight value of each indicator. The λ_{max} values of the judgment matrix of the criterion and solution layers were 4.013, 3.006, 4.011, 6.072, and 3.011, respectively, and the calculated CR values were 0.005, 0.006, 0.004, 0.011, and 0.011. Because the CR values were all less than 0.1, the results were judged to have satisfactory consistency.

The single-layer weight value of the solution layer was multiplied by the single-layer weight value of the corresponding guideline layer to obtain the comprehensive weight value of the program layer. Then, the comprehensive weight ranking of the product design requirements of the growable children's bed was carried out according to the comprehensive weight value, as shown in Table 2.

Table 2. Ranking Scale for Growable Children's Beds

Criterion Layer	Weight	Solution Layer	Weight	CR	Total Weight Value	Ranking
N_1	0.1331	N_{11}	0.6363	0.006	0.0847	3
		N_{12}	0.1877		0.0250	15
		N_{13}	0.1760		0.0234	16
N_2	0.2606	N_{21}	0.1690	0.004	0.0440	11
		N_{22}	0.2433		0.0634	6
		N_{23}	0.2363		0.0616	8
		N_{24}	0.3514		0.0916	2
N_3	0.4137	N_{31}	0.0830	0.011	0.0343	14
		N_{32}	0.1220		0.0505	10
		N_{33}	0.1636		0.0677	5
		N_{34}	0.1010		0.0418	12
		N_{35}	0.0949		0.0393	13
		N_{36}	0.4355		0.1802	1
N_4	0.1926	N_{41}	0.3251	0.011	0.0626	7
		N_{42}	0.3608		0.0695	4
		N_{43}	0.3141		0.0605	9

According to the comprehensive weighting results, functional demands and systemic demands were the two aspects that users were most concerned about in the design of growable children's beds. Safety protection, a stable structure with a robust load-bearing capacity, no corners to prevent bumping, environmental sustainability and other safety considerations were at the forefront. Moreover, a scientific structure, growth ability, parent-child interactions, and cost effectiveness also needed to receive special attention. Therefore, growable children's beds should ensure the stability of the structure, environmental sustainability, anti-bump safety, and scientific design. They should also be able to be dismantled and size-adjustable to meet growability needs as well as provide parent–child interactions and have fun designs.

QFD method to transform design features

Based on the AHP hierarchical analysis model, the user requirements for the product design of the growable children's bed were refined and analyzed into specific design features, which were denoted as U_k (k=1,2,3..., m), as shown in Table 3. The functions and requirements of each scenario level were accompanied by the corresponding specific design features to satisfy their requirements (Fucheng *et al.* 2022). Seven experts, including four teachers in the furniture manufacturing program and three furniture designers, were invited to score the correlation between user needs and design features of the growable children's bed product design. High correlation is scored as 5 and is counted as "●" in the matrix; moderate correlation is scored as 3 and is counted as "■"; weak correlation is scored as 1 and is counted as "▲"; no correlation is scored as 0, which is indicated by no sign.

Table 3. Correspondence Table between User Requirements and Design Features

Target Layer	Criterion Layer	Solution Layer	Design Features
Y	N_1	N_{11}	Rounded modeling U_1
		N_{12}	Soft colors U_2
		N_{13}	Simple and lovely appearance U_3
			Changing appearance U_4
	N_2	N_{21}	Modular design U_5
		N_{22}	Conforming to children's ergonomics U_6
		N_{23}	Modular design U_5
		N_{24}	Robustness and wear resistance U_7
	N_3	N_{31}	High space utilization U_8
		N_{32}	Educational and playful needs U_9
		N_{33}	Modular design U_5
			Changing appearance U_4
		N_{34}	Educational and playful needs U_9
		N_{35}	Modular design U_5
			Lightweight and easy-clean material U_{10}
		N_{36}	Protective facilities U_{11}
	N_4	N_{41}	Robustness and wear resistance U_7
			Modular design U_5
		N_{42}	Nontoxic and harmless materials U_{12}
		N_{43}	Lightweight and easy-clean material U_{10}
			Robustness and wear resistance U_7

The "left wall" and the "ceiling" of the quality house conveyed the needs of users and the design requirements, respectively. The "room" was filled with the correlation scores between the needs of users and the design requirements, and the calculated weights were filled into the "basement". The quality house of growable children's beds is shown in Table 4. The weights of each design requirement are calculated by Eqs. 3 and 4, respectively,

$$F_j = \sum_{i=1}^{n} w_i \times E_{ij} \tag{3}$$

where W_i represents the weight of the i-th indicator, and E_{ij} is the relationship degree value between the i-th user need and the j-th design requirement. Equation 4 is as follows,

$$M_i = \frac{F_j}{\sum_{j=1}^{n} F_j} \tag{4}$$

where F_j represents the absolute importance weight of the design requirements, and M_i represents the relative importance weight of the design requirements.

According to the weight of the importance of quality characteristics in the basement part of the quality house, in the design process of growable children's bed products, the top five design features were modular design (15.8%), robustness and wear resistance (12.3%), protective facilities (10.89%), nontoxic and harmless materials (10.6%), and rounded modeling (9.6%). The weight of these five design features was 59.1%, accounting for a large proportion of the overall design requirements; thus, these design features should be the top design priorities. The design features of conforming to children's ergonomics (8.9%), changing appearance (8.4%), and educational and play needs (6.3%) should also be considered. The results of the present research were in line with the widespread concern among parents regarding durability, wear resistance, and harmless materials, which were consistently highlighted in similar studies (Xu 2023). However, the present experiments also revealed a notable emphasis on modular design, which had emerged as a significant factor in contemporary product design. This discovery would be highlighted in the analysis.

Table 4. Quality House of Growable Children's Beds

		Design Requirements											
User needs	W_i	U_1	U_2	U_3	U_4	U_5	U_6	U_7	U_8	U_9	U_{11}	U_{12}	U_{10}
N_{11}	0.0847	●		▲			▲				▲		
N_{12}	0.0250		●	■									
N_{13}	0.0234	▲	■	●	●					▲			
N_{21}	0.0440				▲	●			▲				▲
N_{22}	0.0634	▲				■	●		▲		■		
N_{23}	0.0616				▲	●	■						
N_{24}	0.0916					▲	▲	●					
N_{31}	0.0343					■			●				
N_{32}	0.0505	▲		▲	■	▲			■	●	▲		▲
N_{33}	0.0677				●	●	■	■	▲	■	▲		
N_{34}	0.0418		▲	▲	■					●			
N_{35}	0.0393	▲		▲	▲	●							●
N_{36}	0.1802	■					▲	▲			●	■	
N_{41}	0.0626			▲	▲	●		●	■	▲		■	▲
N_{42}	0.0695											●	
N_{43}	0.0605				▲	▲		●				■	●
F_j		1.1407	0.2370	0.4709	1.0004	1.8717	1.0614	1.4568	0.6859	0.7506	1.2941	1.2574	0.6561
M_i		0.0960	0.0199	0.0396	0.0842	0.1575	0.0893	0.1226	0.0577	0.0632	0.1089	0.1058	0.0552
Ranking		5	12	11	7	1	6	2	9	8	3	4	10

Construction of scenario FBS model

Through Table 4, the design features with higher scores were extracted and summarized as regulating, protective, and entertainment functions, which guided the FBS mapping process as the functional elements of the growable children's beds. The FBS Hierarchy Mapping on growable children's beds is shown in Fig. 3.

Function-Behavior Transformation (F-B): the extracted sub-functional modules are transformed into specific behavioral modules respectively (Ma and Peng 2021). For example, protective facilities are designed to ensure the safety of children when they flip their body, play, and jump. This step is essential because it bridges the gap between the abstract functions and the tangible behaviors.

Behavior-Structure Transformation (B-S): based on the above functional-behavioral transformation, the contents of the behavioral modules are subdivided into corresponding structural modules. This step is inherently linked to the F-B Transformation, as it translates the desired behaviors into physical structures. Considering that different behaviors may map the same structure, the associated structures should be reasonably combined, which contributes to the compactness of the product's overall structure. For example, the components' detachable structure design is provided to rebuild and change shape.

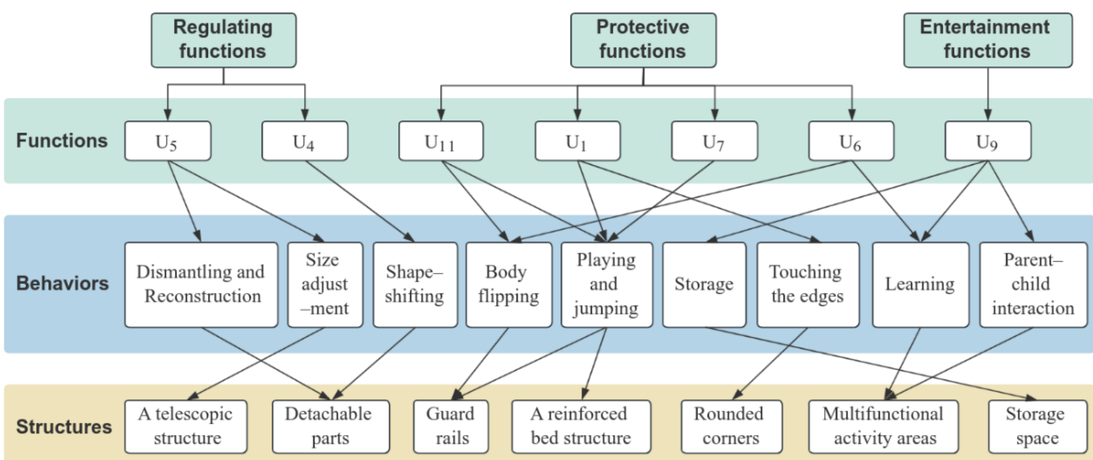

Fig. 3. FBS Hierarchy Mapping on growable children's beds

Practice and Evaluation

Based on the above analysis, the design of a growable children's bed was focused on the three functional modules of adjustability, protection, and entertainment, covering five design features: U_5, U_7, U_{11}, U_{12}, and U_1. Full consideration was given to seven structural modules: a telescopic structure, detachable parts, guard rails, a reinforced bed structure, rounded corners, multifunctional activity areas, and storage space. Considering market demand and the concept of minimalist design, three design schemes for growable children's beds were proposed for children aged 0 to 12 years, namely, F_1, F_2, and F_3. These designs were modular and adaptable, which allowed for size customization. The three schemes are centered on simplicity and practicality. In each case the aim was to meet consumers' needs for basic furniture, while considering space saving and ease of maintenance. The design of Scheme F_1 focused on adjusting the height and length of the bed to meet the needs of the growing child. The dimensions could be adjusted from 140 x

90 cm to 200 x 90 cm. It was made of sturdy materials and had an interesting design with softly rounded corners. The design highlights of Scheme F_2 were the tight protection of the perimeter and the ability to change the shape of the modules by dismantling the parts to meet a variety of growth needs. Scheme F_3 had a semi-open design that considered the growth function as well as the storage function. The telescopic structure under the bed achieved a storage function and could be transformed into a double bed, with the size changing from 200 x 85 cm to 200 x 160 cm. Starting from the simplest bed type, these schemes gradually incorporated adaptability and versatility to suit different family lifestyles and spatial conditions. Figure 4 shows an effect diagram of the specific scheme.

Fig. 4. Effect diagram of the specific scheme

The PUGH decision matrix was used to verify and comprehensively evaluate the design solutions of the growable children's bed and, finally, determined the best design solutions and optimization direction according to the comprehensive score (Li *et al.* 2022), avoiding subjectivity in the design process and improving the scientific nature and satisfaction of the design solutions (Fang *et al.* 2023). First, Scheme F_3 was selected as the benchmark scheme, and 12 users with experience purchasing children's beds were invited to conduct a detailed comparative analysis between the remaining schemes and the benchmark scheme. The users, aged between 25 and 45 years, were equally divided between men and women, which provided a balanced perspective on the product evaluation. The combined net score was calculated based on the PUGH decision matrix. The "+," "−," and "S" symbols were used to rate the options, where "+" represents that the scheme is better than the benchmark scheme, scoring "+1"; "−" indicates that it is slightly worse than the benchmark scheme, scoring "−1"; and "S" represents the same and the score remains unchanged. The PUGH decision matrix of growable children's beds is shown in Table 5.

Table 5. PUGH Decision Matrix of Growable Children's Beds

Evaluation indicators	F_1	F_2	F_3
U_1	+	+	S
U_5	−	+	S
U_7	S	−	S
U_{11}	−	+	S
U_{12}	S	S	S
Total number of "+"	1	3	0
Total number of "S"	2	1	5
Total number of "-"	2	1	0
Net score	−1	2	0
Ranking	3	1	2

The results of the evaluation showed that Scheme F_2 had the highest net score, followed by Schemes F_3 and F_1. Therefore, through this evaluation method, Scheme F_2 was finally adopted as the optimal design solution. The program refinement is shown in Fig. 5.

Fig. 5. Program refinement diagram

Scheme F_2 is made of easy-to-clean, environmentally friendly wood, which protects children's health and growth while helping them feel soothed and relaxed. The shape is curved, with large, rounded corners. A rounded and simple shape prevents children from bumping accidents during play and adds a sense of gentleness and closeness (Zhong and Lin 2020). The overall reinforced bed structure is surrounded by guardrails to increase product safety protection. In use, the product uses a telescopic structure for size adjustment to adapt to different age groups, while the combination of different modules can be spliced into a variety of forms to meet the needs of different functional scenarios, such as sofas and writing desks, thereby increasing the interaction between the child and the parents and the fun aspect. In addition, the product is designed with some storage space, which enables the orderly storage of toys and decorations.

RESULTS AND DISCUSSION

Modular design, as a systematic design method, can meet the demand for flexibility and growth of children's furniture (Ye *et al.* 2021a). Through modular design, children's beds are divided into independent modules. Each module has independent functions and the same port, and users can flexibly combine and interchange them according to their needs (Yu *et al.* 2019). While considering the functions required for children's growth, it also meets the concept of green sustainable development and extends the product life cycle.

This study revealed that appearance, as well as systemic, functional, and economic demands were factors that parents always considered when purchasing children's furniture. Among them, the appearance demands included no corners to prevent harmful bumping, warm colors, and a beautiful shape. System demands included easy assembly, a scientific structure, an adjustable size, and a stable structure with a robust load-bearing capacity. Functional demands included storage, parent-child interaction, growth ability, fun design, easy to clean, and safety protection. Economic demands included cost-effectiveness, environmental sustainability, and durability. Through AHP hierarchical analysis, it was found that system and functional demands were the two aspects that users were most concerned about, especially the safety protection function in the program layer. The ranking of quality characteristics obtained by the QFD quality function also verified that safety factors, such as robustness and wear resistance, protective facilities, nontoxic and harmless materials, rounded modeling, and conforming to children's ergonomics, were still the most important factors for users to consider.

However, due to the limitations of the number of decision-making teams, there are certain subjective limitations in the judgment process. Consequently, it is necessary to use artificial intelligence methods, such as data analysis tools, to identify trends for in-depth analysis and exploration in follow-up studies due to the lack of comprehensiveness in decision-making. This research mainly investigated the structural design of the growth of children’s beds. However, less research has been conducted on the color of growable children’s beds, and the impact of color on children’s psychological, physiological and behavioral development has not been fully explored. Moreover, the market demand for intelligent children’s beds is growing, and this trend indicates a new direction for the future development of the children’s furniture industry (Xu and Xu 2023). Therefore, subsequent studies should pay more attention to the color design of growable children’s beds and explore how to combine intelligent technology with growable children’s beds in the hope of providing children with more comprehensive and intelligent innovative design solutions and providing stronger support for products to stand out in market competition. In addition, the evaluation reveals that, although the telescopic structure in the design solution provides children long-term comfort as they grow, the extension of the crib and the movement of the parts cause some decline in the overall stability and result in wear and tear of the connecting parts. Hence, it is necessary to minimize the adverse effects of these materials by using high-quality materials and a fine mechanical structure.

CONCLUSIONS

1. This study proposed an integrated Analytic Hierarchical Process, Quality Function Development and the Platts Conceptual Decision Matrix (AHP-QFD-PUGH) model to study and analyze the product design for growable children’s beds. The AHP-QFD model was used for quantitative analysis to accurately mine and ranked user needs and product features. The PUGH decision matrix was then used to select the optimal design scheme for the product, which provided an important reference for the subsequent design of children’s furniture in China.
2. In the four criterion layers of AHP hierarchical analysis, functional and systemic demands accounted for the largest proportion, with weights of 0.4137 and 0.2606, respectively. In the solution layer, safety-related factors such as safety protection, a stable structure, no corners to prevent bumping and environmental sustainability were the top items with the larger weight, whose weighted values were 0.1802, 0.0916, 0.0847, and 0.0695, respectively.
3. According to the house of quality (HOQ), the top five design features for growable children’s beds were modular design (15.8%), robustness and wear resistance (12.3%), protective facilities (10.9%), nontoxic and harmless materials (10.6%), and rounded modeling (9.6%). The weighting of these five design features was as high as 59.1%.

4. To further investigate the structural characteristics of products, this study introduced the function-behavior-structure (FBS) model as a supplementary analysis tool. It not only enabled a more comprehensive understanding and optimization of the design of growable children's beds but also aimed to provide innovative ideas and methods in the field of furniture design. Through the FBS model study, the regulating, protective, and entertainment functions were proposed as the functional elements of the design of growable children's beds to implement the structural design strategy. At the same time, it was necessary to fully consider the seven structural modules of a telescopic structure, detachable parts, guard rails, a reinforced bed structure, rounded corners, multifunctional activity areas, and storage space.

REFERENCES CITED

Cui, F. (2024). "Research on product design of elderly intelligent wheelchair based on Kano-QFD and FBS Model," *Master, Shanghai Normal University*.

Fan, W. Y., and Zhao, C. J. (2011). "Study on the development dynamics and trends of children's furniture industry," *Journal of Zhejiang Forestry Science and Technology* 31(4), 70-75.

Fang, M., Yang, W., Li, H., and Pan, Y. (2023). "Enhancing user experience through optimization design method for elderly medication reminder mobile applications: A QFD-based research approach," *Electronics* 12(13), article 2860. DOI: 10.3390/electronics12132860

Fucheng, W., Yang, L., and Jianlin, K. (2022). "Research on design of intelligent agricultural harvester based on QFD and AHP," *International Journal of New Developments in Engineering and Society* 6(1). DOI: 10.25236/IJNDES.2022.060103

Ginting, R., Ishak, A., Malik, A. F., and Satrio, M. R. (2020). "Product development with quality function deployment (QFD): A Literature Review," *IOP Conference Series: Materials Science and Engineering* 1003(1), article 012022. DOI: 10.1088/1757-899X/1003/1/012022

Han, J., Li, J., Jiang, Y., and Wang, L. (2021). "Application of innovative technology in children furniture design," *E3S Web of Conferences*, M. Anpo and F. Song (eds.), 236, article 04059. DOI: 10.1051/e3sconf/202123604059

Han, J., Wei, X. L., Liang, Y. J., Jia, Y. Y., and Ma, W. Y. (2023). "Exploration of aging-ready shower chair design based on KJ-AHP method," *Furniture and Interior Design* 30(9), 40-44. DOI: 10.16771/j.cn43-1247/ts.2023.09.007

Hu, H., and Wang, M. W. (2021). "Elderly bathing product design based on FBS model," *Design* 34(23), 74-77.

Huang, B. T., and Wang, X. (2020). "Modularization-based design of children's beds for growability," *Design* 33(2), 118-120.

Huang, J. S., Liu, L., and Li X. Y. (2022). "Innovative design and evaluation of elderly bathing aids with integrated AHP/QFD/FBS," *Furniture and Interior Design* 29(10), 54-59. DOI: 10.16771/j.cn43-1247/ts.2022.10.010

Jiang, M. L., and Chen, Y. S. (2023). "Analysis of online sales data of children's bunk beds," *Furniture and Interior Design* 44(3), 37-40. DOI: 10.16610/j.cnki.jiaju.2023.03.008

Jiao, R. l., and Zuo, H. l. (2021). "Research and application of integrated QFD/TRIZ/ AHP for designing ageing steel wardrobe," *Machinery* 48(11), 57-64.

Kwong, C. K., and Bai, H. (2002). "A fuzzy AHP approach to the determination of importance weights of customer requirements in quality function deployment," *Journal of Intelligent Manufacturing*, 13, 367-377.

Li, H., Wang, S. Y., and Li, J. l. (2021). "Research on human-machine interface evaluation method based on QFD-PUGH," *Journal of Graphics* 42(6), 1043-1050.

Li, J., Peng, X., Li, C., Luo, Q., Peng, S., Tang, H., and Tang, R. (2023). "Renovation of traditional residential buildings in Lijiang based on AHP-QFD methodology: A case study of the Wenzhi Village," *Buildings* 13(8), article 2055. DOI: 10.3390/buildings13082055

Li, R. R., and Yao, Q. (2021). "Current situation and problems of China's furniture industry," *Forest and Grassland Machinery* 2(4), 53-58. DOI: 10.13594/j.cnki.mcjgjx.2021.04.010

Li, W. K., Zhou, Y. D., and Yang, Y. M. (2023). "Design of intelligent human security gates for high-speed railway stations based on KJ-AHP-QFD," *Hunan Packaging*, 38(6), 137-142. DOI: 10.19686/j.cnki.issn1671-4997.2023.06.034

Li, Y., Ghazilla, R. A. R., and Abdul-Rashid, S. H. (2022). "QFD-based research on sustainable user experience optimization design of smart home products for the elderly: A case study of smart refrigerators," *International Journal of Environmental Research and Public Health* 19(21), article 13742. DOI: 10.3390/ijerph192113742

Liu, B., and Zhu, J.-G. (2023). "Behavior-oriented storage furniture design for preschool children," *Furniture and Interior Design* 44(2), 34-39. DOI: 10.16610/j.cnki.jiaju.2023.02.007

Liu, M., Zhu, X., Chen, Y., and Kong, Q. (2023). "Evaluation and design of dining room chair based on analytic hierarchy process (AHP) and Fuzzy AHP," *BioResources* 18(2), 2574-2588. DOI: 10.15376/biores.18.2.2574-2588

Liu, Y. F., and Wang, W. (2024). "User demand-oriented design of children's growable wardrobe," *Furniture* 45(3), 32-36. DOI: 10.16610/j.cnki.jiaju.2024.03.007

Luo, X. M., Li, W. Y., Huo, M. R., and Yu, D. J. (2023). "Research on children's growing furniture design based on product system design theory," *Footwear Craftsmanship and Design* 3(12), 186–188.

Lyu, J., Chen, R., Yang, L., Wang, J., and Chen, M. (2022). "Applying a hybrid Kano/quality function deployment integration approach to wood desk designs for open-plan offices," *Forests* 13(11), article 1825. DOI: 10.3390/f13111825

Ma, D., and Peng, J. (2021). "Research on the design of traditional kitchenware for people living alone based on the FBS model," in: *2021 2nd International Conference on Intelligent Design (ICID)*, 307-312. DOI: 10.1109/ICID54526.2021.00069

Mai, K. W., Li, C., and Li, Y. R. (2022). "Innovative design of children's bed based on QFD and TRIZ Theory," *Industrial Design* 2, 29-31.

Miao, Y. F., Li, J. J., and Xu Y. J., (2023). "Design and evaluation of pediatric infusion area furniture based on Kano-GRA-AHP," *Furniture and Interior Design* 30(1), 44–49. DOI: 10.16771/j.cn43-1247/ts.2023.01.010

Miao, Y., Yan, S., and Xu, W. (2024). "The study of children's preferences for the design elements of learning desks based on AHP-QCA," *BioResources* 19(2), 2045-2066. DOI: 10.15376/biores.19.2.2045-2066

Nakamura, S., Wind, M., and Danello, M. A. (1999). "Review of hazards associated with children placed in adult beds," *Archives of Pediatrics and Adolescent Medicine*, 153(10), 1019-1023. DOI: 10.1001/archpedi.153.10.1019

Neira-Rodado, D., Ortiz-Barrios, M., De la Hoz-Escorcia, S., Paggetti, C., Noffrini, L., and Fratea, N. (2020). "Smart product design process through the implementation of a Fuzzy Kano-AHP-DEMATEL-QFD approach," *Applied Sciences-Basel* 10(5), article 1792. DOI: 10.3390/app10051792

Nixon, J. D., Dey, P. K., and Davies, P. A. (2013). "Design of a novel solar thermal collector using a multi-criteria decision-making methodology," *Journal of Cleaner Production* 59, 150-159. DOI: 10.1016/j.jclepro.2013.06.027

Qiu, J. P., and Zu, W. L. (2018). "Evaluation analysis of network influence of Chinese university think tanks based on group policy hierarchical analysis," *Modern Intelligence* 38(8), 99-106.

Ren, S. Y., and Zhu, J. G. (2024). "Analysis of CMF design principles for children's furniture," *Furniture and Interior Design* 45(1), 51-55+65. DOI: 10.16610/j.cnki.jiaju.2024.01.010

Sun, Y.-M., Yan, S., and Cai, C.-Y. (2024). "Multifunctional bed design for preschool children under Kano model," *Furniture* 45(3), 27-31. DOI: 10.16610/j.cnki.jiaju.2024.03.006

Tian, D., Ding B. H., and Zhang J. X., (2024). "Research on the design of emergency multifunctional inflatable blanket," *Art and Design (Theory)*, 2(1), 102-105. DOI: 10.16824/j.cnki.issn10082832.2024.01.012

Tong, Y. Y. (2023). "Research on the interaction characteristics of intelligent children's bed based on VIP design law," *Development and Innovation of Machinery and Electrical Products* 36(2), 61-64.

Wan, M., Chen, J., and Toppinen, A. (2015). "Consumers' environmental perceptions of children's furniture in China," *Forest Products Journal* 65(7–8), 395-405. DOI: 10.13073/FPJ-D-14-00102

Wan, M., Zhang, Y., and Ye, W. (2018). "Consumer willingness-to-pay a price premium for eco-friendly children's furniture in Shanghai and Shenzhen, China," *Forest Products Journal* 68(3), 317-327. DOI: 10.13073/FPJ-D-17-00050

Wang, Y. (2022). "Research on the application of color in children's furniture design," *Chemical Fiber and Textile Technology* 51(5), 189-191.

Wei, P., and Madina, Z. (2022). "Application of environmentally friendly materials in the design of children's furniture based on Fuzzy Technology," *Mathematical Problems in Engineering* 5165699. DOI: 10.1155/2022/5165699

Wei, W., Tang, S., and Huang, R. (2023). "The design of a community new energy vehicle shared charging service system based on the KJ-AHP method," in: *HCI International 2023 – Late Breaking Papers*, V. G. Duffy, H. Krömker, N. A. Streitz, and S. Konomi (eds), Cham, 436-449. DOI: 10.1007/978-3-031-48047-8_29

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

Wu, X., and Zhang, Z. (2022). "The post-pandemic era study on the design of high-speed railway seats," in: *Design, User Experience, and Usability: Design Thinking and Practice in Contemporary and Emerging Technologies*, M. M. Soares, E. Rosenzweig, and A. Marcus (eds.), pp. 265-278. DOI: 10.1007/978-3-031-05906-3_20

Xia J., (2022). *Modularization-based Design of Children's Growth Beds*, Master Thesis Nanchang University. DOI: 10.27232/d.cnki.gnchu.2021.001848

Xiong, T. T., Lin, Y. X., and An, X. Q. (2023). "Design of tracked mobile crusher based on AHP-QFD theory," *Machine Design* 40(S2), 27-32. DOI: 10.13841/j.cnki.jxsj.2023.s2.001

Xu, J., and Xia, C. (2023). "Application of quality function deployment and theory of inventive problem solving in the human-pet shared furniture design process," in: *2023 International Conference on Culture-Oriented Science and Technology (CoST)*, 61-66. DOI: 10.1109/CoST60524.2023.00022

Xu, R., and Xu, B. M. (2023). "Visualization and analysis of domestic children's furniture research situation based on Citespace," *Furniture and Interior Design* 44(5), 20-24. DOI: 10.16610/j.cnki.jiaju.2023.05.004

Xu, Z. D. (2023). *Research on Crib Design Based on TRIZ Theory and Patent Avoidance Method*, Master's thesis, Nanjing Forestry University. DOI: 10.27242/d.cnki.gnjlu.2023.000856

Xuan, J., Xu, B., and Li, B. (2021). "Design method for visually impaired people travel aids based on Kano model," in: *2021 2nd International Conference on Intelligent Design (ICID)*, 417-421. DOI: 10.1109/ICID54526.2021.00088

Yan, C.-Y. (2023). *Research on the Application of Children's Furniture Design Based on the Concept of Sustainability*, Master's thesis, Shenyang University of Aeronautics and Astronautics. DOI: 10.27324/d.cnki.gshkc.2023.000557

Ye, J., Li, W., and Yang, C. (2021a). "Research on modular design of children's furniture based on scene theory," in: *Human-Computer Interaction. Design and User Experience Case Studies*, M. Kurosu (ed.), pp. 153-172. DOI: 10.1007/978-3-030-78468-3_11

Ye, X., Li, X., Qin, Y., Chen, J., and Pei, J. (2021b). "Design and research on growing children's furniture," *Scientific Journal of Humanities and Social Sciences* 3(9), 141-145

Yu, F., (2010). "Talking about the design of growable children's furniture," *Art and Design (Theory)* 2(4), 185-187. DOI: 10.16824/j.cnki.issn10082832.2010.04.067

Yu, G., Dai, C., Huang, S., Gan, L., and Gao, W. (2019). "Research on innovative application of modular design in university student apartment furniture," *IOP Conference Series: Materials Science and Engineering* 573(1), article 012016. DOI: 10.1088/1757-899X/573/1/012016

Zhang, H., and Xu, W., (2020). "Online sales of children's beds research and design analysis," *Forestry Machinery and Woodworking Equipment* 48(12), 65-69.

Zhang, X. Y., and Xu, W. (2023). "Emotional design of children's furniture based on AHP," *China Forest Products Industry* 60(6), 70-75. DOI: 10.19531/j. issn1001-5299.202306012

Zhang, Z., Zhang, L., and Ding, W., (2023). "A study of obstetric waiting seat design based on QFD-Kano and FBS," *Furniture and Interior Design* 30(1), 38-43. DOI: 10.16771/j.cn43-1247/ts.2023.01.009

Zhao, Y., and Xu, Y. (2023). "Evaluation model for modular children's wooden storage cabinet design," *BioResources* 18(4), 7818-7838. DOI: 10.15376/biores.18.4.7818-7838

Zhong, G. M., and Lin, X. R. (2020). "Research on the development and design of growable children's furniture based on fun," *Furniture and Interior Design* (1), 24-25. DOI: 10.16771/j.cn43-1247/ts.2020.01.006

Zhu, T.-L., Li, Y.-J., Wu, C.-J., Yue, H., and Zhao, Y.-Q. (2022). "Research on the design of surgical auxiliary equipment based on AHP, QFD, and Pugh decision matrix," *Mathematical Problems in Engineering* 2022, article 4327390. DOI: 10.1155/2022/4327390

Zhu, Y. F. (2022). "Research on multifunctional children's bed design for two-child family based on KANO and TRIZ," *Packaging Engineering* 43(20), 220-227. DOI: 10.19554/j.cnki.1001-3563.2022.20.024

Article submitted: June 13, 2024; Peer review completed: August 17, 2024; Revised version received: August 23; Accepted: August 25, 2024; Published: September 9, 2024.
DOI: 10.15376/biores.19.4.8084-8102