A Data-Driven Design Framework for Smart Wooden Dressing Mirrors for Single Young Adults Integrating PESTEL-Kano-FBS Model

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GRAPHICAL ABSTRACT

A Data-Driven Design Framework for a Smart Wooden Dressing Mirror Integrating PESTEL-Kano-FBS Models

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In response to the growing demand for smart household products, this study focused on the intelligent design optimization of a wooden dressing mirror that integrates traditional wood craftsmanship with smart home technologies. A data-driven design framework was developed by combining the PESTEL model, Kano demand analysis, and the Function-Behavior-Structure (FBS) model to address the personalized requirements of young single adults. PESTEL analysis identified market opportunities in sustainable wooden products and digital home integration, while the Kano model quantified and categorized user demands. The FBS model then transferred these demands into functional attributes, forming a comprehensive demand–function mapping framework. An empirical study with 16 young single adults employed semi-structured interviews and questionnaires. The results showed that (1) the Kano questionnaire had high reliability and validity (KMO > 0.92, Bartlett's $p < 0.001$, Cronbach's $\alpha > 0.92$); (2) seventeen needs were classified as Must-be, One-dimensional, Attractive, and Indifferent, with "virtual fitting" showing the highest satisfaction sensitivity (0.734), and (3) the FBS model effectively guided the functional translation into hardware and software. The proposed PESTEL–Kano–FBS framework provides a practical approach for developing sustainable, user-centered smart wooden household products.

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Keywords: Wooden household products; Data-driven design; PESTEL-Kano-FBS model; Dressing mirror design; Single young adults

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INTRODUCTION

Wooden household products have long been among the most widely used and economically significant categories of home products worldwide (Global Growth Insights 2024). The common categories of wooden household products are clocks, coat racks, decorative frames, and mirrors, all of which demonstrate wood's versatility in both structural and aesthetic applications. Among them, wooden mirrors represent a distinctive intersection between utility and artistry, functioning not only as reflective tools but also as expressive interior elements that shape spatial ambience. In both Eastern and Western interior design traditions, wooden frames have been preferred for mirrors. In medieval Europe, intricately carved wooden frames symbolized craftsmanship and social status (Shephard 2013), while in traditional Chinese households, hardwoods such as rosewood or elm were prized for their stability, tactile comfort, and compatibility with lacquer or inlay techniques, producing mirrors that blended durability with cultural refinement (Wang 1986). Compared with those framed in metal, plastic, or glass, wooden mirrors offer a favorable strength-to-weight ratio, high processability, and natural warmth that create a distinctive tactile and visual experience (Ross 2010). These material qualities, together with wood's environmental friendliness, have ensured the enduring popularity of wooden mirrors in everyday life. Their natural grain, soft color tone, and organic texture further enrich interior spaces with a sense of warmth and aesthetic harmony, enhancing both visual comfort and emotional attachment (Burnard and Kutnar 2015).

However, despite these advantages, traditional wooden designs often fall short of meeting the growing demand for intelligent and responsive living environments (Feng and Su 2025). As lifestyles evolve toward greater individualization and digitalization, the need for smart, user-adaptive wooden household products and related home products has become increasingly prominent (Fewella 2024). The global rise in solo living has significantly influenced household composition. Recent data indicate that single-person households now exceed 40% in several Northern European countries and account for more than 30% in many Western European and North American nations (Eurostat 2020; OECD 2021). In the United States, such households represented 28% of all households in 2020, which is twice the proportion recorded in 1960 (U.S. Census Bureau 2021). Similar trends are evident in East Asia, where over 40% of young residents in Tokyo live alone (MIC 2020), and South Korea anticipates continued growth in single-person households (KOSIS 2022). Although this lifestyle offers greater independence, it is also closely associated with loneliness and psychological stress (Park and Lee 2019; Lim *et al.* 2023; Hwang 2021), fueling the emergence of the "loneliness economy," which encompasses smart home technologies designed to provide emotional support (Zhou *et al.* 2020; Han and Kim 2021). Within this context, young adults living alone increasingly seek intelligent household products that not only support daily routines but also enhance emotional well-being (Vuohijoki *et al.* 2023). For dressing mirrors in particular, user expectations have moved beyond the conventional role of traditional wooden mirrors toward designs that integrate personalized feedback, emotional interaction, and adaptive smart functions (SMART PRODUCTS: Technological Applications vs., n.d.).

The smart home market is expanding rapidly and is projected to surpass USD 230 billion by 2029 (Seo *et al.* 2016; Markets and Markets 2023). This trend is driven in part by the demand for personalized and emotionally engaging products (Fortune Business Insights 2026). Smart mirrors are evolving from simple reflective devices into multifunctional interactive platforms. Earlier applications primarily focused on fitness and beauty (Fatima *et al.* 2024), but recent developments have extended their functions to include health monitoring, telemedicine integration (Huang *et al.* 2021), skincare analysis (Lee *et al.* 2022), and even fall detection for the elderly (Chiu and Lee 2018). These systems are transitioning from "passive displays" to "proactive services" that support daily life, health management, and emotional well-being (Liu and Zhang 2023). However, key limitations persist, including insufficient personalization, superficial emotional interaction, and inadequate attention to user privacy (Storr *et al.* 2017; Li *et al.* 2022).

In recent years, researchers in product design and consumer behavior have employed diverse analytical frameworks to improve the systematicity and explanatory power of design research, bridging macro-environmental factors, user needs, and conceptual design. At the macro level, the PESTEL model, a critical tool for environmental context analysis, has been used to identify how political, economic, social, technological, environmental, and legal factors shape design and market dynamics. De Sousa *et al.* (2022) refined each PESTEL dimension by decomposing macro-environmental variables into specific elements such as production costs, consumer subsidy policies, and local government incentives, thereby identifying potential "bottlenecks" and "breakthroughs." Bilgram and Laarmann (2023) applied the PESTEL framework to examine the influence of generative AI during product prototyping, while Morris *et al.* (2021) used PESTEL analysis to categorize barriers in wastewater reuse projects, emphasizing the need to consider all six dimensions in design and implementation.

At the user level, the Kano model, a classic method for identifying and classifying user needs—has been continually adapted to emerging design contexts. Shi and Peng (2021) integrated satisfaction data from online reviews into the Kano model to improve need classification accuracy in product design. Tandiono and Rau (2023) developed an enhanced framework combining the Kano model, environment-oriented QFD, and TRIZ (Theory of Inventive Problem Solving) at the component level. Kang and Qu (2021) coupled Kano categorization with a QFD optimization model to balance functional performance and affective experience. Addressing the inefficiencies of traditional survey-based Kano models, Joung and Kim (2022) introduced explainable neural networks to automate the classification of product features. Similarly, Soenandi *et al.* (2021) integrated Kansei Engineering with the Kano model to capture users' emotional responses to desktop organizers and identify key satisfaction attributes.

At the conceptual design level, the Function-Behavior-Structure (FBS) model has been widely applied to establish logical mappings among function, behavior, and structure, enhancing systematic reasoning and knowledge transfer in design processes. Luo *et al.* (2023) emphasized that explicitly mapping these relationships ensures logical coherence and adaptability. Through fuzzy reasoning, the model can handle uncertain or incomplete information, yielding flexible and adaptive design solutions. Guo *et al.* (2021) applied FBS theory to improve functional resilience in uncertain environments by enabling structural reasoning and mapping. Han *et al.* (2021) used the FBS model as a structured semantic network to organize design concepts through the three-tiered hierarchy of function, behavior, and structure, thereby facilitating more effective retrieval, analogy, and concept generation. Russo and Spreafico (2023) further demonstrated how a macro-level FBS model could guide structural innovation in greenhouse cover systems through topological triggers.

The PESTEL, Kano, and FBS models each demonstrate unique strengths in macro-environmental analysis, user need identification, and conceptual design, respectively, forming a multi-level analytical foundation for sustainable product design research. Smart mirrors are currently transitioning from utilitarian products to emotional companions; however, existing studies still exhibit gaps in emotional interaction and user behavior integration. For young adults living alone, psychological and social needs remain insufficiently addressed (Seo *et al.* 2016; Luo *et al.* 2023). Prior research has often focused on the isolated application of these models, lacking an integrated, cross-level perspective that combines external environmental factors (PESTEL), user-perceived needs (Kano), and product conceptual mapping (FBS).

In existing studies, PESTEL analysis is frequently employed as a background tool for assessing market feasibility or industrial environments, with conclusions often remaining descriptive and difficult to operationalize in design decision-making (Schomaker and Sitter 2020). In contrast, this study treats each PESTEL dimension as an exogenous variable with both constraining and guiding effects, and converts them into actionable design input conditions through a systematic mapping mechanism. Within China's policy and legal environment, initiatives such as "digital living," "proactive health," and personal information protection legislation are not abstract slogans; they directly delimit the functional boundaries, data processing modes, and interaction logic of the smart dressing mirror. At the socio-cultural level, young single adults' high mobility, fast-paced lifestyles, and needs for emotional companionship not only shape functional directions but also profoundly influence product morphology, modular configuration, and modes of emotional interaction. Through this transformation process, PESTEL evolves from a macro-level explanatory tool into a pre-decision mechanism that actively drives innovation direction.

After incorporating macro constraints into the design system, this study further applies the Kano Model to structurally stratify young users' needs, thereby avoiding the common problem of "feature-stacking" design. Unlike conventional approaches in which the Kano Model directly guides feature addition or reduction (Zhang *et al*. 2024), in this research it functions as a mechanism for demand screening and priority restructuring under constrained conditions. Once PESTEL constraints are clarified, certain features that might initially appear attractive, such as cloud-dependent facial recognition services, may be intentionally deprioritized due to privacy risks or regulatory uncertainty. At the same time, functions that are typically considered supplementary in smart home products, including privacy visualization controls and physical shielding mechanisms, may be reinterpreted as one-dimensional or even essential qualities within particular legal and social contexts. Thus, the Kano Model no longer merely reflects subjective user preferences but co-constructs a more realistic and feasible demand structure together with the macro-institutional environment.

Within this study, the FBS Model plays a critical role in translating the above analytical outcomes into concrete design solutions. Unlike prior research that primarily applies FBS as a conceptual design analysis tool (Fu *et al*. 2024), this study emphasizes its capacity for parameter mapping under complex constraints. Specifically, core demands filtered through the PESTEL-Kano dual mechanism are first defined at the functional level, such as health trend feedback, outfit decision support, and emotional interaction. These functions are subsequently translated into assessable behavioral objectives, including local data processing, low learning-cost interaction, and adaptation to high-frequency short-duration use. Finally, they are implemented at the structural level through design parameters such as modular folding structures, physically controllable sensor components, and portable installation mechanisms. This process ensures that design outcomes are not driven by intuition or stylistic preference but are rationally derived under multiple real-world constraints.

To address these gaps, the present study proposes an integrated PESTEL–Kano–FBS framework that enables the quantification and transformation of emotional needs into design attributes for smart wooden household products. Specifically, the PESTEL analysis identifies market opportunities and external drivers at the macro level, the Kano model stratifies users' emotional and functional needs, and the FBS model maps these needs to corresponding functional, behavioral, and structural attributes. Based on these analytical linkages, the study further applies the framework to the intelligent enhancement of a traditional wooden dressing mirror, transforming it from a passive reflective object into an interactive platform that integrates emotional feedback and adaptive smart functions. This integration establishes a closed-loop mechanism from need identification to design implementation, enabling emotional and intelligent factors to be systematically embedded within the wooden household products design process.

In the context of the parallel advancement of China's "Dual Carbon" strategy, the digital economy, and platform-based consumption, single-dimensional user demand analysis is no longer sufficient to support design research with practical feasibility. By systematically integrating the macro-institutional environment, users' subjective experiences, and design engineering logic, design innovation is not merely a passive response to external constraints; rather, through structured methodologies, constraints can be transformed into directional innovation resources.

The core of this study lies in constructing a systematic design decision-making framework that progressively translates macro-contextual constraints (PESTEL) into meso-level demand structures (Kano Model) and further into micro-level design parameters (FBS Model). This framework overcomes the fragmentation commonly observed in prior design research, where macro-environmental analysis, user demand analysis, and specific design solutions remain disconnected, thereby establishing a logical closed loop from policy context to product structure. From a methodological perspective, the value of the PESTEL-Kano-FBS framework extends beyond a single product case. It provides a transferable and reusable research pathway for innovation within complex socio-technical systems. The framework is particularly applicable to intelligent products heavily influenced by policies and regulations, interactive systems involving sensitive issues such as privacy, health, or emotion, and products targeting specific social groups whose needs vary significantly across contexts. By constructing a macro-meso-micro transmission logic, this study offers a systematic paradigm for building a verifiable and interpretable theoretical bridge between institutional constraints and technological innovation in design research.

EXPERIMENTAL

Research Subject

This study investigated the needs, pain points, and expectations of young adults living alone with respect to smart dressing mirrors, particularly focusing on the intelligent enhancement of traditional wooden mirrors in the context of clothing coordination. To this end, semi-structured interviews were conducted with 16 young adults representing diverse demographic backgrounds and living arrangements. Detailed participant characteristics are provided in Table 1.

PESTEL Method

The PESTEL macro-environmental analysis method is a key tool for driving product innovation (De Sousa *et al.* 2022). It assists designers in systematically identifying product opportunities by examining the external environment across six dimensions: political, economic, social, technological, environmental, and legal. These dimensions together constitute the PESTEL framework (Fig. 1).

Questionnaire Survey

This questionnaire survey targeted young adults living alone, encompassing diverse occupations, income levels, and lifestyles. In addition to collecting basic demographic data, the questionnaire adopted a dual-question format derived from the Kano model, asking respondents about their feelings when a feature is present and their reactions when it is absent (Fig. 2). This design enabled the evaluation of user perceptions toward core features such as virtual try-on and outfit-sharing interactions.

Table 1. Participant Characteristics

Characteristic	Details	N / Proportion	Notes
Research Location	Fuzhou Area	16 (100%)	All participants were residents of Fuzhou City
Total Participants	Total number of interviewees	16	-
Gender Distribution	Male	7 (44%)	-
	Female	9 (56%)	-
Age Range	20-30 years old	16 (100%)	Represents the target demographic of single young adults
Duration of Living Alone	≥ 1 year	16 (100%)	Ensuring participants had significant experience with living alone
Occupational Distribution	Internet Industry	5 (31%)	Product Managers, Software Engineers
	Creative Industry	4 (25%)	Designers, Content Creators
	Freelance	4 (25%)	Remote Workers, Independent Consultants
	Others	3 (19%)	Education, Healthcare, Finance
Living Arrangement	Renting	13 (81%)	Includes apartments, shared single rooms, etc.
	Homeownership	3 (19%)	Self-owned property
Living Space Area	Renting: 26 m²-56 m²	13 (81%)	Reflects typical urban rental apartment sizes in Fuzhou
	Homeownership: 55 m²-79 m²	3 (19%)	Reflects typical urban homeownership sizes in Fuzhou
Interview Objective	To understand the needs, pain points, and expectations of young adults living alone in Fuzhou regarding clothing matching and smart dressing mirrors	-	Core objective of the study

Data collection employed both online and offline approaches. Online questionnaires were distributed through the Wenjuangxing platform, while offline surveys were administered in youth apartments and office areas to better capture the group's specific needs and purchasing capacity.

Face-to-face communication during the offline phase allowed researchers to clarify questions in real time, thereby improving response quality and data reliability. A total of 200 questionnaires were distributed, with 177 valid responses obtained, resulting in an effective response rate of 88.5%.

Fig. 1. PESTEL Model

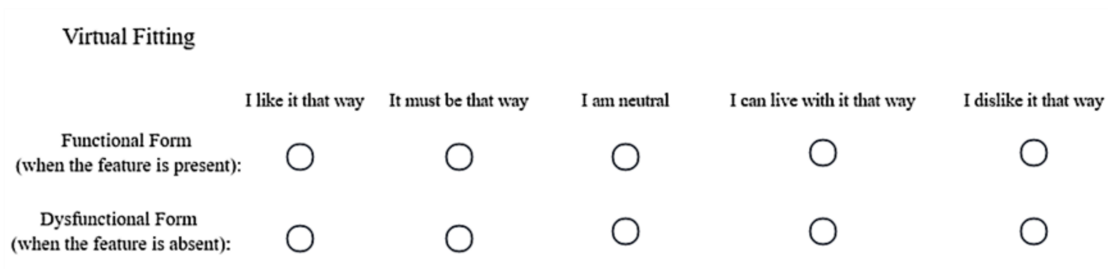


Fig. 2. Two-way questioning structure based on the Kano model

Kano Model

The Kano model, proposed by Professor Noriaki Kano of Tokyo Institute of Technology (Kano *et al.* 1984), is a widely recognized method for classifying and prioritizing user needs. It provides a systematic approach to understanding user requirements, optimizing product design, and improving user satisfaction and loyalty. Based on the relationship between demand attributes and satisfaction levels, the model classifies user needs into five categories: Must-be (M), One-dimensional (O), Attractive (A), Indifferent (I), and Reverse (R). The primary strength of the Kano model lies in its ability to elucidate how different types of product attributes influence overall user satisfaction (Fig. 3).

Must-be attributes represent the basic expectations that customers take for granted, their absence leads to strong dissatisfaction, yet their fulfillment merely prevents complaints rather than enhancing satisfaction. One-dimensional attributes exhibit a linear relationship with satisfaction, where improved performance proportionally increases satisfaction and poor performance results in dissatisfaction. Attractive attributes correspond to unexpected or novel features that delight users when present but do not cause dissatisfaction when absent. Indifferent attributes have little or no impact on customer satisfaction, as users remain largely unaffected by their inclusion or omission. In contrast, Reverse attributes decrease satisfaction when present, often due to unnecessary complexity, redundancy, or a mismatch with user expectations and preferences (Berger *et al.* 1993; Matzler and Hinterhuber 1998).

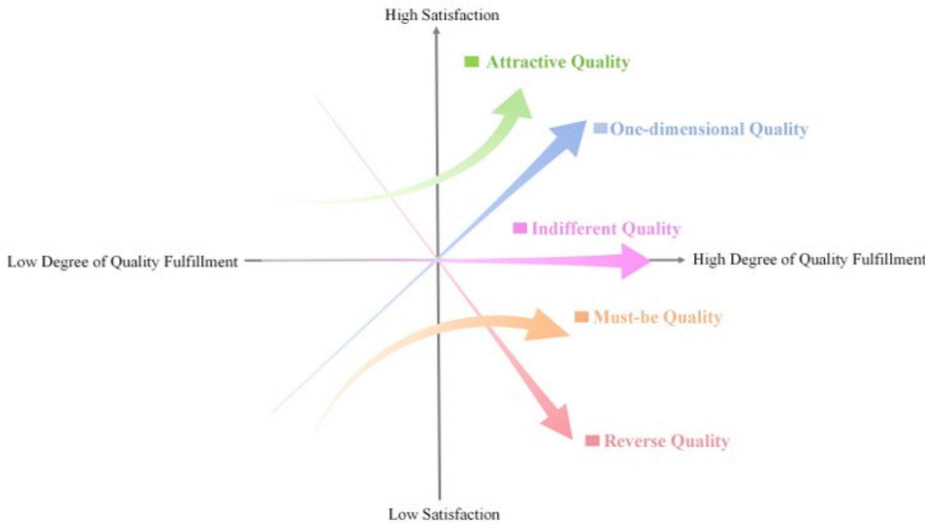


Fig. 3. The relationship between Kano demand attributes and user satisfaction

In practical research and application, the Kano model typically employs questionnaire surveys to collect user feedback. In recent years, online questionnaires have gained widespread adoption due to their broad coverage and high response efficiency, enabling more effective acquisition of demand perceptions across different user groups, thereby enhancing the accuracy and representativeness of model analysis. The computational formula is commonly expressed as membership degree, which quantifies the relationship between user needs and satisfaction. The expression for membership degree K is as follows,

$$K = \frac{X}{M+O+A+I} \quad (X = M,\ O,\ A,\ I) \tag{1}$$

where A, O, M, and I are the total frequencies of responses for the Attractive, One-dimensional, Must-be, and Indifferent categories, respectively. The A, M, O, I in the Better-Worse coefficients appearing below are the same as this.

The relationship between different types of needs and user satisfaction, often referred to as the Better-Worse coefficient, is commonly expressed by the following formulas.

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

$$\text{Worse}=\frac{O+M}{A+O+M+I}\cdot(-1) \tag{3}$$

The sensitivity coefficient ω is calculated as follows:

$$\omega=\sqrt{\text{Better}^2+\text{Worse}^2} \tag{4}$$

Kaiser-Meyer-Olkin (KMO) Test

Before conducting factor analysis, the Kaiser–Meyer–Olkin (KMO) test is a necessary step to assess whether the data are suitable for factor analysis and to avoid invalid analytical results (Kaiser 1974). The KMO statistic ranges from 0 to 1, with values closer to 1 indicating stronger correlations among variables and greater suitability of the data for factor analysis (Cerny and Kaiser 1977). The Cronbach's alpha (α) coefficient serves as a key indicator for measuring the internal consistency reliability of scales or questionnaires, and it is widely applied in fields such as market research. Its value also ranges from 0 to 1, with higher values indicating stronger inter-item correlations and better reliability (Cronbach 1951),

$$\alpha=\frac{k}{k-1}\left(1-\frac{\sum_{i=1}^{k}\sigma_{Y_i}^2}{\sigma_X^2}\right) \tag{5}$$

where k denotes the total number of items in the scale, $\sigma_{Y_i}^2$ represents the variance of the score for the i-th item, and σ_X^2 denotes the variance of the total score across all items.

In practical applications, a standardized Cronbach's α value greater than or equal to 0.7 is generally considered to indicate acceptable reliability of the scale. The corresponding calculation is as follows,

$$\alpha_{standardized}=\frac{k\cdot\bar{\gamma}}{1+(k-1)\cdot\bar{\gamma}} \tag{6}$$

where k denotes the total number of items in the scale, and $\bar{\gamma}$ represents the average inter-item correlation coefficient.

Function-Behavior-Structure (FBS) Model

The Function-Behavior-Structure (FBS) model provides an effective framework for translating user requirements into design solutions. Originally proposed by Gero (1990), it has become a foundational tool for describing the conceptual design process and remains highly influential in product design research (Gero and Kannengiesser 2004). The model consists of three interrelated and hierarchically organized components: Function, Behavior, and Structure. Together, these components form the logical foundation for transforming abstract requirements into concrete design representations (Fig. 4). When applied under complex design conditions, the FBS framework enables designers to systematically analyze how functional objectives are achieved through behavioral mechanisms and structural configurations.

Within the FBS model, a strong logical relationship exists among the three elements. Function defines behavior, and behavior determines structure. In other words, the functional requirements of a product define the behaviors needed to achieve those functions, and the corresponding structure is then designed based on these behaviors. At the same time, structure facilitates behavior, and behavior enables the implementation of function. The structure of a product dictates the behaviors it can exhibit, and these behaviors ultimately fulfill the intended functions. This interconnected and mutually reinforcing relationship forms a closed loop that guides product design from user needs to tangible product forms, ensuring alignment with user expectations (Gero and Kannengiesser 2004). Whereas conventional models primarily establish connections between function and behavior, the FBS model emphasizes the role of structure, which not only enables behavior but also provides the foundation for exploring a broader spectrum of potential behaviors (Fig. 5).

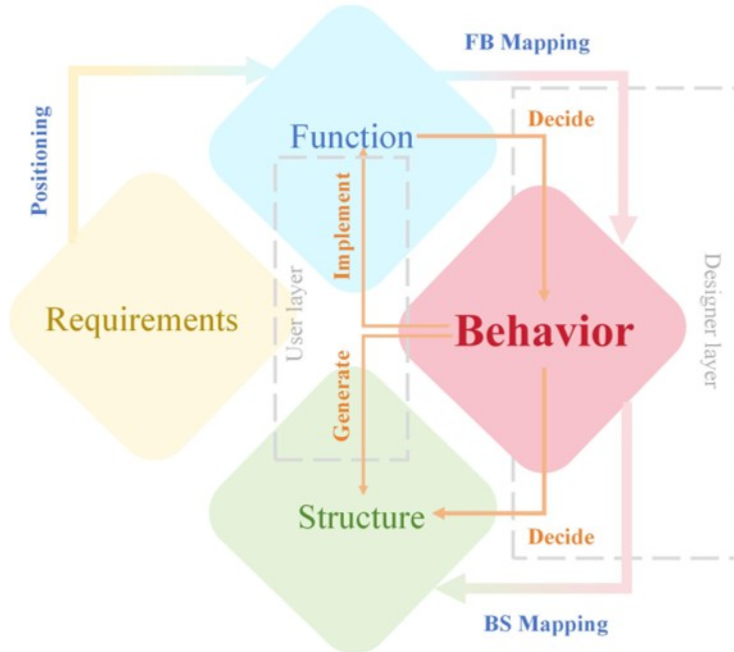


Fig. 4. FBS mapping framework

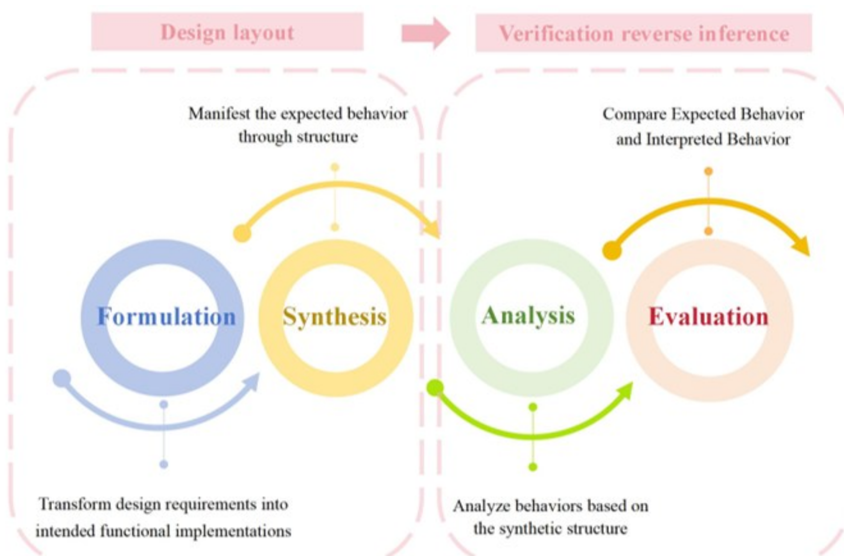


Fig. 5. FBS operation phase

Research Framework

This study proposes a "PESTEL-Kano-FBS" triadic integration framework (Fig. 6), which is structured as follows: PESTEL environmental scanning, followed by Kano-based demand grading, FBS-driven functional implementation, prototype validation, and finally, design practice. The framework integrates PESTEL macro-environmental analysis to define design boundaries, the Kano model to prioritize user requirements, and the FBS model to translate those requirements into functional solutions, thereby establishing a systematic and stepwise design methodology.

Focusing on the PESTEL-Kano-FBS model, the study applies this integrated framework to the intelligent enhancement of a traditional wooden dressing mirror for single young adults. Product opportunities and market gaps were initially identified through a PESTEL analysis, followed by a classification of user needs using the Kano model. A "Requirement–Functionality" mapping framework was subsequently developed. Based on this framework, user research was conducted through semi-structured interviews with 16 representative single young adults, complemented by a survey of 200 questionnaires, which yielded an effective response rate of 88.5%.

This process identified core user needs, including virtual try-on, outfit recommendations, and social sharing, while also establishing functional priorities. Based on these insights, a multifunctional smart wooden dressing mirror was developed, integrating virtual try-on, health data tracking, intelligent styling, and social interaction. The results highlight the practical and theoretical value of the PESTEL-Kano-FBS model in guiding the intelligent transformation of traditional wooden household products, offering a robust methodological reference for user-centered innovation and sustainable smart home product development.

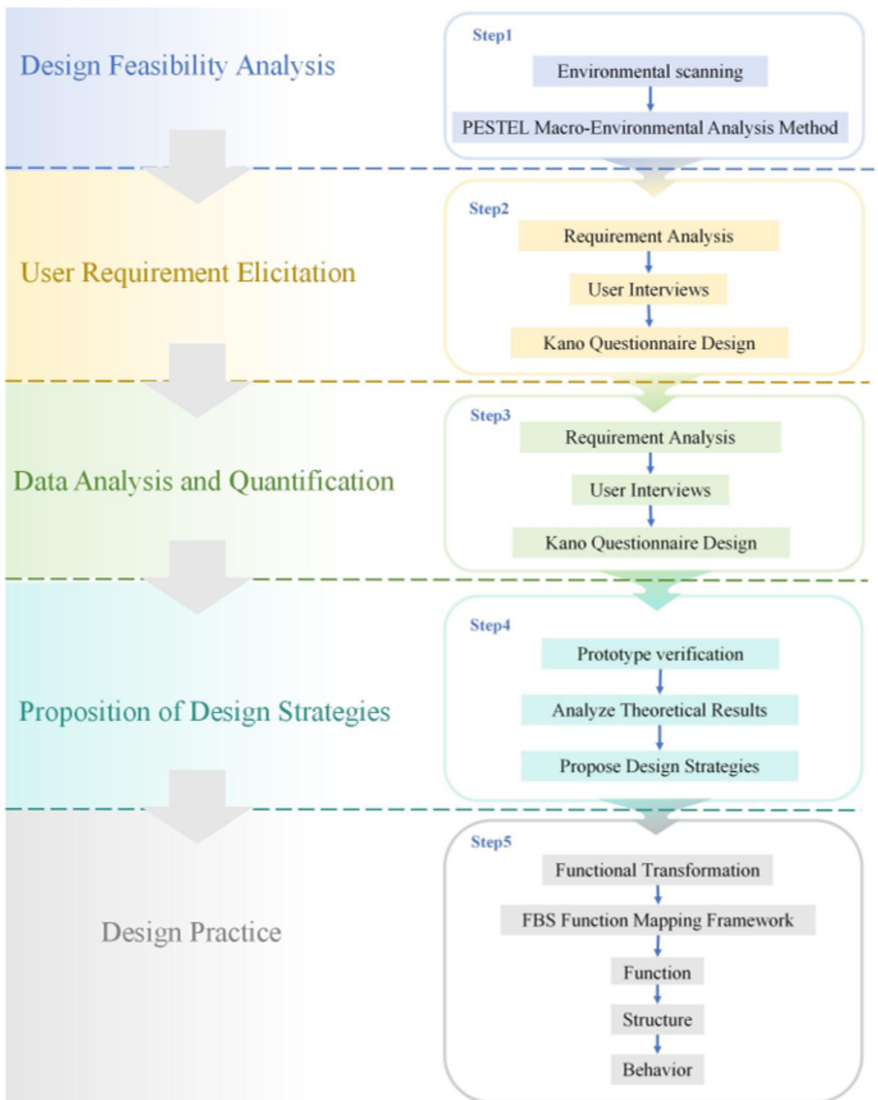


Fig. 6. Research design

RESULTS

PESTEL Environmental Scan

To ensure that the design solution for the smart dressing mirror tailored to single young adults integrates strategic foresight and market competitiveness, an in-depth environmental assessment was conducted using the PESTEL model (Table 2). This analytical framework facilitated the identification of key external drivers shaping product and supported the derivation of targeted design strategies and potential market opportunities.

Behavioral Patterns and Emotional Needs of Single Young Adults

This study conducted in-person, semi-structured interviews with sixteen young adults living alone. The discussions were organized around three primary themes. The first theme examined clothing-related behaviors, including purchasing channels and challenges in outfit coordination. The second explored patterns of smart product usage, addressing the types of devices used, frequency of use, satisfaction levels, and expectations. The third focused on perceptions and expectations of smart dressing mirrors, assessing participants' familiarity with such products, desired functionalities, and preferences regarding form and interaction methods. The semi-structured approach ensured comprehensive topic coverage while allowing participants flexibility for open expression. Each interview lasted approximately 30 minutes and was systematically documented.

Through interviews, this study identified the typical usage pathway of smart dressing mirrors among young adults living alone in pre-departure scenarios. This pathway is structured chronologically into five stages: the awareness activation stage, the screening and matching stage, the interactive try-on stage, the final confirmation stage, and the departure stage (Fig. 7). At each stage, the figure presents users' specific behaviors, emotional fluctuations, contextual characteristics, and corresponding pain points, thereby constructing a comprehensive scenario-based emotional framework. At the behavioral level, users transition from low to high engagement. The process begins with checking the weather while still in bed, followed by browsing clothing in front of the wardrobe, repeatedly trying on outfits, adjusting details, and ultimately confirming their overall appearance. In terms of emotional dynamics, users' affective states are not linearly stable; rather, they shift dynamically as tasks progress, reflecting the continuous psychological impact of outfit decision-making under time pressure. Regarding contextual characteristics, different stages exhibit differentiated situational conditions. The early stage is marked by high time pressure, fragmented information, and heightened spatial awareness. The middle stage emphasizes embodied human-computer interaction with greater physical participation. The later stage places greater emphasis on aesthetic confirmation as well as the sense of security and preparedness that emerges from the integration of functional performance and evaluative feedback. Accordingly, user pain points demonstrate a progressive evolution across different stages, beginning with challenges in integrating fragmented information, followed by the high costs associated with repeated try-on processes, and ultimately culminating in constraints related to the observation of fine details. By systematically juxtaposing user behaviors, emotional fluctuations, and specific usage contexts, this analysis establishes a situational foundation for the subsequent identification of user needs and elucidates the differentiated functional and emotional roles undertaken by the smart dressing mirror across diverse usage scenarios.

Table 2. Macroeconomic Environment Analysis Based on the PESTEL Model

Dimension	Content
Political	The Chinese government is vigorously promoting the integration of the "digital lifestyle" and "proactive health" concepts among young populations. The 14^{th} Five-Year Plan for Digital Economy Development (Poo 2021) explicitly proposes fostering emerging forms of digital consumption, such as smart home systems and wearable devices (Zhang 2023), and encourages the development of intelligent terminals that significantly enhance quality of life (Chen *et al*. 2021). This policy environment provides a solid foundation for the market promotion of smart dressing mirrors targeted at urban youth. In response to the growing health anxiety and self-management demands of young people, the Healthy China 2030 Plan Outline emphasizes a shift from a "treatment-centered" to a "health-centered" approach, advocating the use of wearable devices for daily posture monitoring and exercise intervention. This orientation directly supports the development of features such as the "health trend report" and posture-tracking functions embedded in the proposed product (Wang *et al.* 2025). Moreover, under the "dual carbon" strategy, the Implementation Plan for Promoting Consumption issued by the National Development and Reform Commission and other authorities explicitly encourages the younger generation to adopt low-carbon lifestyles and provides policy incentives for energy-efficient smart home appliances (Zhang and Shu 2023).
Legal	User privacy protection represents a fundamental concern in the design of intelligent products. The Personal Information Protection Law of the People's Republic of China (Yang 2022), the Data Security Law of the People's Republic of China, and the Regulations on the Administration of Network Data Security establish strict compliance requirements for the collection, use, and storage of personal information (Creemers 2022). As smart dressing mirrors process highly sensitive biometric data, including posture characteristics and facial information, together with users' lifestyle preferences during operation, privacy protection must be embedded at the core of the design logic (Liu *et al*. 2022). In accordance with the Personal Information Protection Law of the People's Republic of China, the processing of sensitive personal information requires obtaining separate consent from individuals and complying with the principle of data minimization (Wang *et al*. 2022). To reduce the risk of data breaches, this study proposes several design strategies. First, edge computing is adopted to enable localized data processing and storage, thereby minimizing cloud transmission. Second, de-identification and encryption technologies are applied to personally identifiable information to enhance data security. Third, a physical camera shutter mechanism is incorporated at the hardware level to strengthen user control over visual data collection. Through these measures, the design ensures that users can enjoy digital convenience while fully exercising their rights to informed consent and autonomous decision-making, ultimately achieving lifecycle control over their sensitive personal data.
Economic	The rise of the "loneliness economy" and "self-reward consumption" is accelerating the expansion of emerging markets. With the growing size of the single population, single-person households have become a significant component of China's urban social structure (He and Wang 2024). Compared with traditional family units, urban single youth in China exhibit a higher marginal propensity to consume and are more willing to pay for innovative products that provide emotional comfort, aesthetic experiences, and everyday convenience (Li 2025). According to the *China Smart Home Device Market Quarterly Tracking Report*, the scale of China's smart home market continues to expand, showing a transition from "whole-house intelligence" toward "individualized and emotionally oriented smart products." However, many domestic smart products remain at the stage of basic functional aggregation and have yet to effectively address the deeper emotional needs of young consumers (Hu and Zhang 2024). The smart dressing mirror proposed in this study integrates practical functions such as real-time weather updates, personalized outfit recommendations, and schedule management, while incorporating emotional design elements. In this way, the dressing mirror is no longer merely a cold household appliance; rather, it functions as a companion-like

	"intelligent steward." By enhancing the daily efficiency of young urban residents in fast-paced cities such as Fuzhou, it also strengthens their sense of emotional well-being and psychological security within the home environment through interactive feedback (Zhang *et al*. 2023).
Social	The lifestyles of contemporary urban youth in China are increasingly shaped by strong tendencies toward efficiency orientation and individualized expression (Huang and Xu 2023). Within the context of a fast-paced urban environment, young people pursue maximum convenience in daily commuting and social engagements, while also seeking to articulate their identities through distinctive fashion choices. As the world's largest e-commerce market, China exhibits an exceptionally high level of reliance on online apparel shopping among its youth population, with the online penetration rate of clothing categories remaining consistently elevated (Wong *et al*. 2024). Nevertheless, persistent pain points, including uncertainty regarding fitting outcomes and the high costs associated with returns and exchanges, continue to constrain the overall consumption experience (Huang et al. 2023). The smart dressing mirror proposed in this study aligns closely with the digital consumption habits of Chinese youth. The system generates personalized outfit recommendations based on user-specific tags and incorporates aesthetic trends derived from domestic social e-commerce platforms such as Xiaohongshu and Douyin, thereby providing thematic suggestions tailored to particular social scenarios, including festive gatherings and job interviews. By integrating virtual try-on technology with authentic user review data from online retail platforms, the smart dressing mirror transforms from a simple display interface into an intelligent hub that combines decision support functions with aesthetic interaction capabilities, effectively addressing the complexity of decision-making in online apparel purchases.
Technological	The rapid maturation of cutting-edge technologies in China, including artificial intelligence (AI) (Wang 2024), augmented reality (AR) (Zhao *et al*. 2025), and three-dimensional body scanning (Li 2023), has provided solid technical support for the iterative development of smart health-oriented home products. Benefiting from China's well-established computer vision industrial ecosystem, AI technologies are capable of accurately analyzing users' body dimensions and aesthetic preferences and, when combined with consumption big data from domestic e-commerce platforms, generating highly targeted outfit recommendations (Fu *et al*. 2023). At the same time, the application of AR technology enables high-fidelity virtual try-on experiences, significantly reducing trial-and-error time for young people living in fast-paced urban environments, a capability that closely aligns with the efficiency-oriented lifestyles of youth populations in first- and second-tier cities such as Fuzhou (Chen *et al*. 2024). As typical digital natives, Chinese youth demonstrate strong adaptability to and trust in emerging technologies, and the country has established a solid social foundation in AI applications and mobile interaction design (Wang 2024), which further facilitates the integration of intelligent systems into everyday life. These technological advancements not only accelerate the market penetration and user adoption of smart wearable dressing mirrors in the domestic context but also provide mature industrial chain support for transforming such products from laboratory prototypes into practical applications within everyday home environments.
Environmental	Against the macro-policy backdrop of China's advancement of its dual carbon goals, namely carbon peaking and carbon neutrality, addressing resource waste caused by excessive clothing consumption has become an essential component of green development (Zhu *et al*. 2024). In the context of fast-paced e-commerce consumption, urban youth in China have accumulated substantial quantities of idle garments, leading to significant resource redundancy (Li *et al*. 2024). The smart dressing mirror proposed in this study responds to this challenge by integrating a digital wardrobe management function, through which AI-driven algorithms reanalyze and recombine users' existing clothing items to generate new outfit suggestions, thereby operationalizing the circular consumption concept of revitalizing old garments. This function not only reduces clothing idleness and curbs impulsive purchasing behavior but also facilitates the local diffusion of sustainable fashion practices. Furthermore, within the broader framework of China's dual carbon strategy, urban youth in large and

	medium-sized cities often adopt a highly mobile, rental-based lifestyle characterized by frequent relocation and lightweight living arrangements, while traditional dressing mirrors, which are typically fragile and bulky, are easily discarded during moves and thus contribute to increased solid waste (Sun 2025). In response, the present design incorporates a modular folding structure and tool-free assembly to enhance portability and durability, and this long-lifespan, relocation-friendly strategy extends the product lifecycle, reduces repetitive purchases associated with frequent moves, mitigates resource waste, and promotes environmentally responsible lifestyles at the micro level.

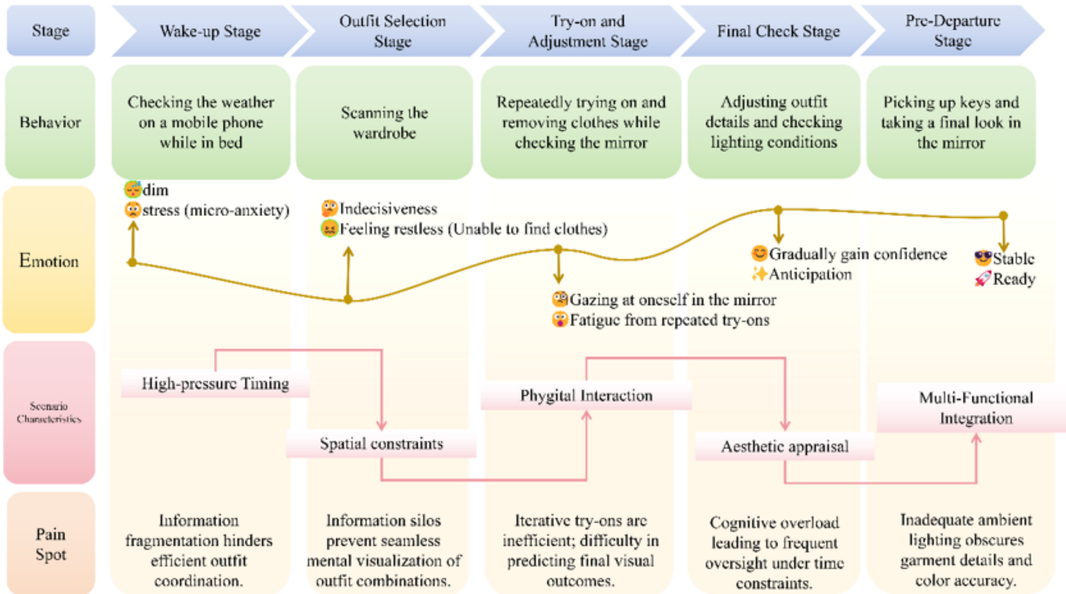


Fig. 7. Contextual evolution across the morning dressing journey

Analysis of the interviews revealed three key behavioral characteristics of single young adults: fragmented time management, intensive spatial utilization, and dual-track consumption decision-making (Fig. 8).

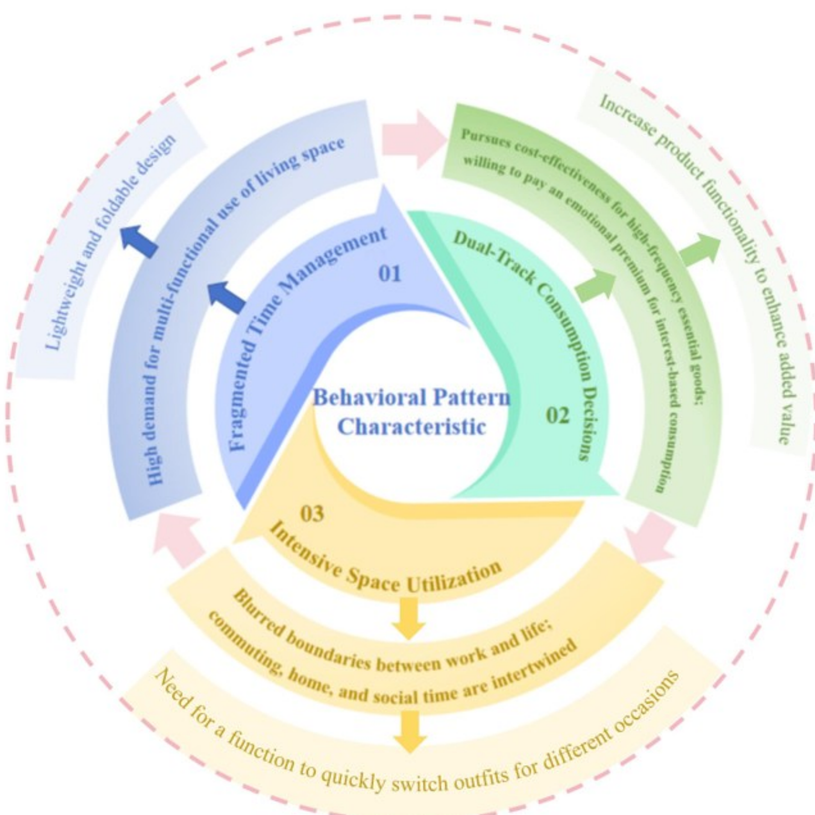


Fig. 8. Behavioral patterns of young adults living alone

Regarding time management, the findings suggest incorporating efficient solutions such as quick-change functions. For living spaces, the need for aesthetic appeal and spatial efficiency indicates that dressing mirrors should adopt highly adaptable and compact designs. Concerning consumption habits, while users tend to seek value for money in daily necessities, they are willing to pay a premium for products that provide emotional value.

Young adults living alone experience pronounced emotional challenges, including loneliness, substantial life pressures, and a strong drive for self-actualization. Consequently, they seek emotional companionship, stress relief, and social recognition. Their psychological needs can be conceptualized as comprising both explicit and implicit demands (Fig. 9). Beyond functioning as a conventional full-length mirror, it is essential to systematically investigate and address these implicit needs. Emotional requirements may be met through features that facilitate social interaction, provide personalized recommendations, and enable the projection of virtual avatars.

The categorization of user needs in this study is informed by David McClelland's iceberg model of competence. "Efficiency anxiety" is classified as a surface-level need because it pertains to users' explicit cognitive concerns at the level of tool utilization. In contrast, "identity reconstruction" and "loneliness compensation" are categorized as deep-level needs, as they involve the individual's self-concept and underlying motives (McClelland 1974). According to this theoretical framework, deep-level traits are difficult to measure directly, yet they constitute the underlying causes that drive observable surface behaviors. Based on McClelland's iceberg model, this study differentiates between surface needs that users can clearly articulate and deep needs that are embedded within recurrent behavioral patterns. Although aesthetic identification and efficiency anxiety are frequently expressed by single-person households as explicit motivations for using smart dressing mirrors, deeper psychological drivers, including loneliness compensation, identity reconstruction, and stress relief achieved through light social interaction, are often difficult to verbalize directly but consistently manifest in actual usage behaviors. The design strategy proposed in this study seeks to translate these latent motivational structures into actionable interaction mechanisms through a process of behavioral mapping.

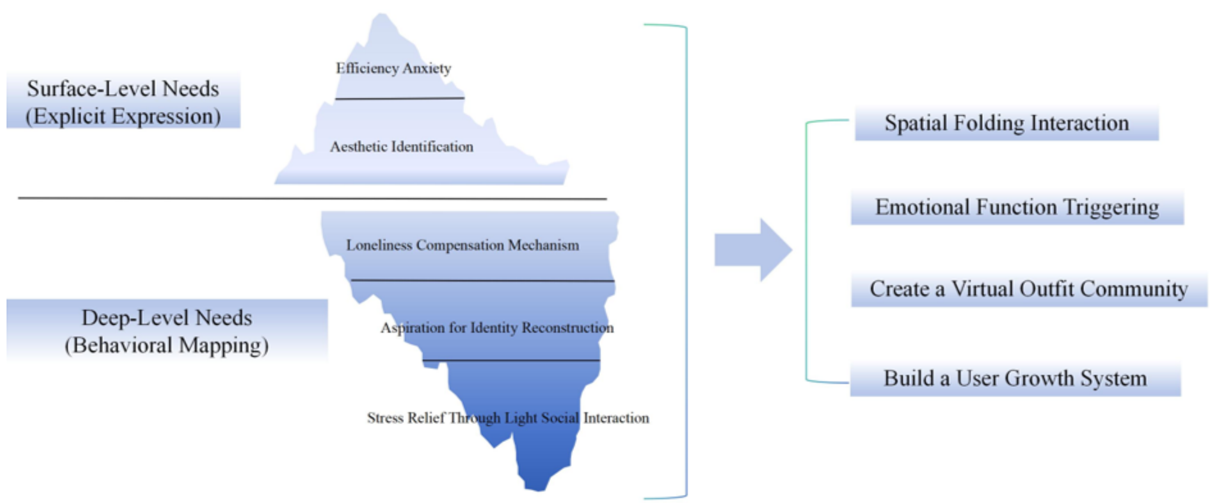


Fig. 9. Deep psychological needs of young people living alone

Based on the PESTEL model and an analysis of the needs of single-person households, 17 preliminary design requirements were identified (Table 3). Some of these requirements reflect functional considerations, while others capture emotional dimensions within the user experience, which were primarily derived through observation and interpretation of behavioral patterns. These requirements were subsequently categorized using the Kano model into basic, performance, attractive, indifferent, and reverse attributes. This classification provides a more nuanced reference for the design process, facilitating the promotion of functional innovation while better aligning with users' aesthetic preferences and experiential expectations.

Table 3. Initial Requirements Items

No.	Initial Requirement Items
01	Virtual Try-on
02	Style Recommendation
03	Data Linkage to Mainstream E-commerce Platforms
04	Companion Mobile App
05	Voice Control
06	Multi-scenario Simulation
07	Social Interaction
08	Gamified Experience
09	Lightweight Device
10	Multi-purpose Expansion
11	Simulation of Ethnic/Holiday Themed Outfits
12	Fashion News and Trend Updates
13	Easy to Transport/Carry
14	Sleek and Simple Appearance
15	Modular Design
16	User Privacy Protection
17	Hidden Camera

User Needs Analysis Based on the Kano Model

After collecting the questionnaires, the raw Kano data were processed, and the KMO test was conducted prior to analysis (Table 4). For positive responses, Cronbach's α was 0.927 (standardized Cronbach's α = 0.922), approaching 1, indicating strong internal consistency. For negative responses, Cronbach's α was 0.924 (standardized Cronbach's α =0.922), again exceeding the 0.7 threshold and demonstrating strong reliability. The validity analysis further confirmed the suitability of the data. The KMO value for positive responses was 0.944, and Bartlett's sphericity test was highly significant (χ^2 = 1649.2, df = 136, $p < 0.001$). For reverse-scored responses, the KMO value was 0.928 with a significant Bartlett's test (χ^2 = 1462.8, df = 136, $p < 0.001$). These results indicate that the dataset is appropriate for factor analysis.

Table 4. Test of Construct Validity

Dimension	Cronbach's α	Standardized Cronbach's α	Items	KMO Value	Bartlett's Test of Sphericity		
					Approximate Chi-Square	df	p-value
Positive Items	0.927	0.922	17	0.944	1649.2	136	<0.001
Negative Items	0.924	0.922	17	0.928	1462.8	136	<0.001

Overall, the questionnaire exhibited robust reliability and construct validity, effectively capturing the needs of young adults living alone and providing a solid foundation for subsequent analysis.

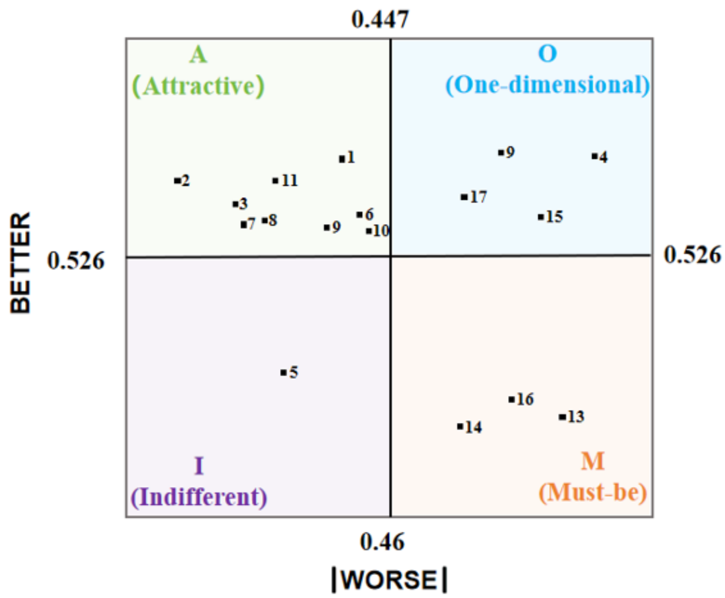


Fig. 10. Better-worse coefficient quadrant diagram

Kano Demand Classification and Ranking

Following aggregation, the requirements were clearly classified into three Must-be, four One-dimensional, nine Attractive, and one Indifferent attribute. Indifferent and reverse attributes were excluded from further analysis due to their limited influence on user satisfaction. To further evaluate the influence intensity of different requirement attributes on user satisfaction, the Better–Worse coefficients and sensitivity values were calculated (Fig. 10), and the detailed calculation results are presented in Table 5. The Better coefficient reflects the extent to which user satisfaction increases when a requirement is fulfilled, whereas the Worse coefficient indicates the degree of dissatisfaction caused when the requirement is not satisfied. In these formulas, $\boldsymbol{A}$, $\boldsymbol{O}$, $\boldsymbol{M}$, and $\boldsymbol{I}$ respectively represent the frequencies of Attractive, One-dimensional, Must-be, and Indifferent responses in the Kano evaluation results. Based on the Better–Worse coefficients, the sensitivity value ($\boldsymbol{K}$) was further derived to quantify the overall impact of each requirement attribute on user perception and satisfaction. Taking Requirement No.1 (Virtual Try-on) as an example, its Better coefficient was 0.601 and its Worse coefficient was −0.422, resulting in a sensitivity value of $\boldsymbol{K = 0.734}$. The related calculation results are shown in Table 5. A higher sensitivity value indicates that the corresponding requirement exerts a stronger influence on user satisfaction and product perception. The results showed that Virtual Try-on ranked first among all requirement attributes in terms of sensitivity, confirming its dominant role in enhancing user experience and perceived product innovation. Furthermore, this method not only enables the classification of requirement attributes, but it also reveals the differences in contribution levels of various requirements to user satisfaction, thereby providing a quantitative basis for subsequent design decision-making.

Table 5. Analysis of Kano Questionnaire Data

No.	A[1]	O[2]	M[3]	I[4]	R[5]	Q[6]	BETTER	WORSE	KANO Attribute	Sensitivity	Rank[7]
01	62	42	31	38	4	0	0.601	-0.422	A	0.734	1
02	77	19	32	36	13	0	0.585	-0.311	A	0.663	5
03	62	26	29	40	20	0	0.561	-0.350	A	0.661	6
04	37	61	34	30	15	0	0.605	-0.586	O	-	-
05	27	42	22	76	10	0	0.413	-0.383	I	-	-
06	66	23	46	25	17	0	0.556	-0.431	A	0.703	2
07	75	17	44	34	7	0	0.541	-0.359	A	0.649	8
08	61	30	31	45	9	1	0.545	-0.365	A	0.656	7
09	30	66	17	45	19	0	0.608	-0.525	O	-	-
10	65	28	47	32	5	0	0.541	-0.436	A	0.695	3
11	73	28	37	35	4	0	0.584	-0.376	A	0.695	3
12	61	25	40	33	18	0	0.541	-0.409	A	0.678	4
13	42	24	75	34	2	0	0.377	-0.566	M	-	-
14	36	23	57	45	16	0	0.366	-0.497	M	-	-
15	38	55	38	38	8	0	0.550	-0.550	O	-	-
16	39	29	63	42	4	0	0.393	-0.532	M	-	-
17	29	61	18	50	19	0	0.570	-0.500	O	-	-

[1] A=Attractive (Delight);[2] O=One-dimensional (Expected);[3] M=Must-be (Basic);[4] I=Indifferent;[5] R=Reverse;[6] Q=Questionable.[7] "Rank" is based on the descending order of Sensitivity values for Attractive and One-dimensional attributes.

The questionnaire data comprehensively captured users' perceptions of each requirement under both functional realization and absence conditions. Based on these evaluations, the satisfaction improvement coefficient (Better/Satisfaction Coefficient) and dissatisfaction elimination coefficient (Worse/Dissatisfaction Coefficient) were calculated to determine the Kano attribute and priority level of each requirement. After classifying all 17 requirements, the analysis results clearly revealed the core expectations of single young adults toward the intelligent modules of smart wooden dressing mirrors., as illustrated in Figure 11. In this figure, the X-axis represents the Better coefficient, and the Y-axis represents the Worse coefficient. The diameter of each bubble is determined by the sensitivity coefficient, while the color corresponds to the Kano category: green indicates Attractive (A) requirements, blue represents One-dimensional (O) requirements, purple denotes Indifferent (I) requirements, and orange corresponds to Must-be (M) requirements. The numbers inside the bubbles indicate the identifiers of the 17 Kano items.

A total of nine requirements were identified as Attractive (A) attributes: Virtual Try-on (No.1), Style Recommendation (No.2), Data Linkage to Mainstream E-commerce Platforms (No.03), Multi-scenario Simulation (No.6), Social Interaction (No.07), Gamified Experience (No.8), Multi-purpose Expansion (No.10), Simulation of Ethnic/Holiday-themed Outfits (No.11), and Fashion News and Trend Updates (No.12). The numerical dominance of these nine features indicates that product innovation should prioritize functions capable of delivering surprise, emotional engagement, and enhanced user experience-key factors in strengthening market competitiveness and fostering user loyalty. In addition, four requirements were categorized as One-dimensional (O) attributes, namely Companion Mobile App (No.4), Lightweight Device (No.9), Modular Design (No.15), and Hidden Camera (No.17). These functions require continuous optimization, as performance improvements directly and linearly translate into higher user satisfaction. Among these features, the companion mobile app (No. 4) requires particular attention in the design process. It exhibits a *Worse* coefficient of -0.586, the highest absolute value among all requirements, indicating that its absence or suboptimal performance would lead to a substantial drop in user satisfaction. As an expected attribute with a high negative weight, optimizing this feature can linearly enhance user delight; however, its failure poses the greatest risk of user churn. Therefore, design resources should be preferentially allocated to this requirement to prevent strong negative feedback arising from functional deficiencies. Meanwhile, three requirements were identified as Must-be (M) attributes: Easy to Transport/Carry (No.13), Sleek and Simple Appearance (No.14), and User Privacy Protection (No.16). The absence of these essential features would lead to pronounced user dissatisfaction, making them fundamental prerequisites for market entry and baseline quality assurance. Finally, No.05 was classified as an Indifferent (I) attribute, indicating that the presence or absence of this function exerts minimal influence on user satisfaction. In terms of functional prioritization, Virtual Try-on (No.1) ranked first with the highest sensitivity value (0.734) and a Better coefficient of 0.601, confirming it as the most innovative and influential feature in product design. It was followed by Multi-scenario Simulation (No.06) with a sensitivity value of 0.703 (Rank 2). Simulation of Ethnic/Holiday-themed Outfits (No.11) and Multi-purpose Expansion (No.10) both achieved a sensitivity value of 0.695, sharing Rank 3. These findings highlight that young adults living alone place the greatest emphasis on attractive attributes that evoke emotional resonance, enable social substitution, and provide virtual enjoyment. Regarding dissatisfaction reduction, Companion Mobile App (No.4) exhibited the strongest potential negative impact, with a Worse coefficient of -0.586, underscoring the need for design attention.

Overall, the Kano model analysis offers robust and precise data support for subsequent concept transformation and functional architecture development based on the FBS model.

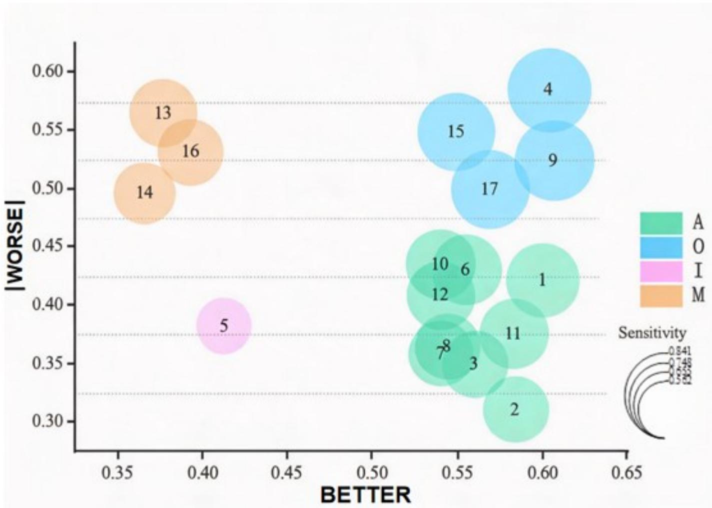


Fig. 11. Kano classification bubble diagram

Interaction Behavior Prediction Based on FBS

Based on the FBS mapping framework, user needs are positioned as the starting point for product functions, which in turn generate expected behaviors that are ultimately realized within the product structure. Interactions with smart dressing mirrors therefore occur across multiple dimensions, most notably gesture-based operations and companion app interactions, with each playing a critical role in distinct functional scenarios.

Driven by consumption-oriented needs, users expect virtual try-on capabilities prior to purchasing clothing. In this context, gesture controls provide an efficient means for rapid outfit changes and scene transitions. For example, users can wave to switch virtual garments or swipe to navigate between options, with the corresponding touchpoints implemented in the hardware structure, specifically within the camera and display modules. Regarding social needs, users anticipate virtual community interaction through the dressing mirror, resulting in behaviors such as sharing outfits, liking, and commenting. These behaviors are primarily supported by the software structure *via* the companion application.

Accordingly, requirement items, expected functionalities, anticipated behaviors, and product structure elements were systematically integrated (Table 6), thereby constructing the comprehensive FBS mapping framework (Fig. 12).

This study adopted a user-centered approach to systematically derive the interaction design logic for the smart dressing mirror. The design pathway begins with the user and progresses through four hierarchical levels: need identification, function extraction, behavior mapping, and structural implementation, thereby constructing a continuous design derivation framework from “human needs” to “object structure” (Fig. 12). Through scenario analysis, the study identifies the core concerns of young adults living alone in their outfit decision-making process and classifies them as interaction and consumption needs.

Table 6. FBS Project Integration

Requirement (R)	Expected Function (F)	Resulting Behavior (B)	Product Structure (S)
R01 Safety	F01 Virtual Try-on	B01 Check weather, holidays	S1 Hardware Structure
R02 Interaction	F02 Style Recommendation	B02 One-click jump to purchase page	S1-1 Mirror Module
R03 Consumption	F03 E-commerce Platform Data Integration	B03 Share outfits, friend likes/comments	S1-2 Display Module
R04 Personalization	F04 Companion Mobile App	B04 Scan to generate body report	S1-3 Stand Module
R05 Social	F05 Multi-scenario Simulation	B05 Get information	S1-4 Camera Module
R06 Health	F06 Social Interaction	B06 Measure and Record Body Dimensions	S1-5 Lighting Module
R07 Aesthetic	F07 Gamified Experience	B07 Take photos to create an e-wardrobe	S2 Software Structure
-	F08 Modular Design	B008 Foldable Mirror for Transport	-
-	F09 Lightweight Device	B09 Match with friends	-
-	F10 Sleek Appearance	B10 Wave to switch clothes	-
-	F11 Multi-purpose Expansion	B11 Daily Check-in	-
-	F12 Themed Outfit Simulation	B12 Turn Camera On/Off	-
-	F13 Fashion News Updates	-	-
-	F14 Easy to Transport	-	-
-	F15 User Privacy Protection	-	-
-	F16 Hidden Camera	-	-

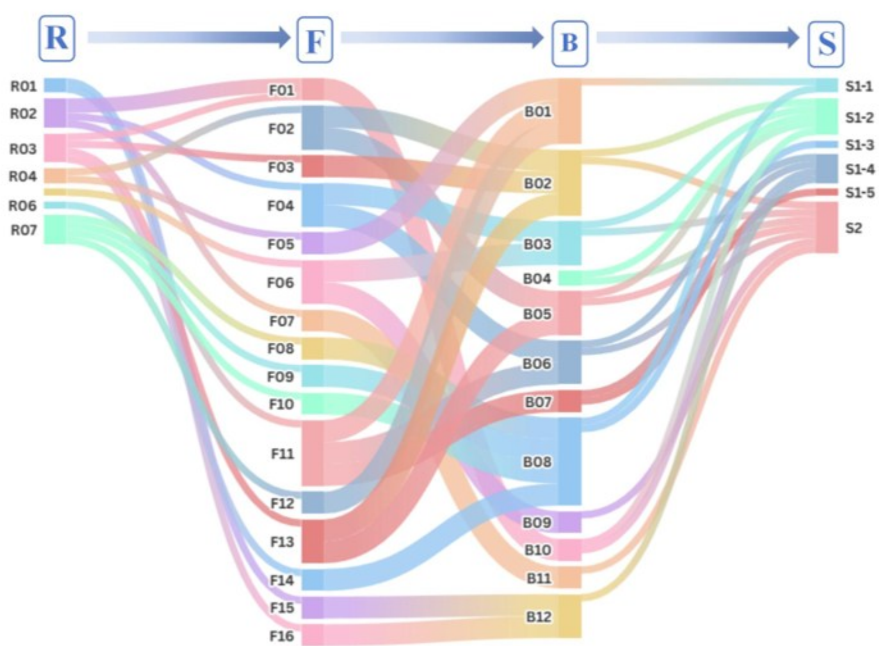


Fig. 12. FBS mapping derivation framework

At the needs level, these requirements are further translated into specific product functionalities (Fig. 13). Among them, virtual try-on emerges as a key functional module that addresses multiple demands, particularly mitigating high try-on costs and fragmented information. At the functional layer, behavior mapping clarifies the concrete modes of user–system interaction. Users perform actions such as changing outfits through physical movements, reducing explicit operational burden while maintaining interaction continuity. Finally, at the structural layer, these interactive behaviors are realized through implementable system components: camera modules capture user movements, and display modules present real-time virtual try-on effects, completing a closed-loop correspondence among behavior, function, and structure.

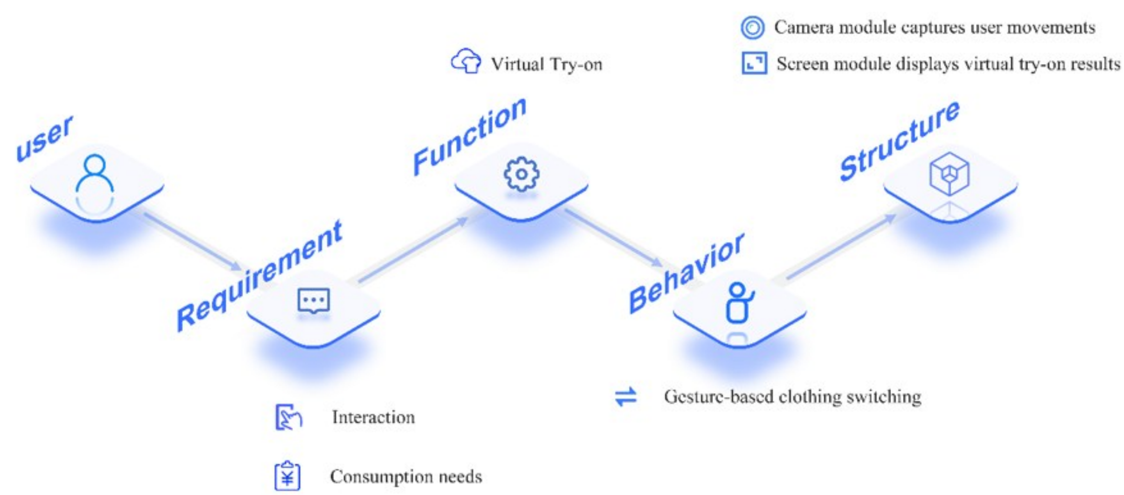


Fig. 13. Derivation path diagram from user to structure

Building a Smart Wooden Dressing Mirror Software Framework Based on Behavioral Prediction

The companion app was designed to address attractive (charm) attribute requirements and is organized around five core modules: Home, Shop, Wardrobe, Community, and Me. The Home section provides fashion trend updates and integrates a one-click purchase function for apparel and accessories. Prior to purchasing, the Wardrobe section supports virtual try-on, offering two options for body modeling: manual input of body dimensions or camera-based 3D body scanning. Within the same interface, users can catalog their existing garments by photographing them. Visualization of the digital wardrobe enables AI algorithms to generate novel outfit combinations, thereby reducing unnecessary purchases and mitigating impulsive consumption.

In addition, the upper interface layer displays holiday and weather information, allowing the system to generate occasion-specific outfit suggestions and provide weather-aware clothing care advice. Once satisfactory outfits are created, users can share them on the virtual social platform, Community, where they may view peers' posts, participate in local topic discussions, and connect with "outfit buddies" who share similar aesthetic preferences. Finally, the Me section integrates body management functions: if abnormal measurements or posture deviations are detected, the system automatically pushes notifications to users, offering personalized health and posture reminders (Fig. 14).

Fig. 14. Construction of the smart dressing mirror software framework based on FBS. (a) App entry page, including logo and slogan design; (b) Redirect to mainstream e-commerce platform clothing purchase page; (c) Fashion news page; (d) Virtual try-on page; (e) Dimension recording interface; (f) Find nearby friends interface; (g) Dynamic posting interface; (h) Match friends with similar style interface; (i) Outfit diary interface; (j) Record existing clothing and intelligent matching interface.

The system is not merely a touchscreen display but employs a depth camera to capture users' skeletal point data. When standing at a standard try-on distance of 1.2 to 1.5 m, users' hand gestures are translated into a virtual cursor on the interface. The smart dressing mirror's gesture interaction design follows ergonomic principles, mapping core functions to natural movements (Fig. 15): page wake-up and home navigation are performed with an open-palm gesture, mimicking a greeting toward the mirror for rapid activation; horizontal switching, such as selecting clothing or scenes, uses a horizontal swipe following the forearm's natural arc for smooth operation; confirmation or selection is executed via an air tap/push gesture, intuitively simulating a click to confirm; scrolling or vertical browsing is achieved through a vertical swipe requiring only small wrist movements to reduce arm fatigue; and exit or return is handled with a crossed-arms gesture, leveraging the universal cognitive mapping of "end" or "close" for intuitive understanding. This integrated design ensures that interactions are both intuitive and easy to use while adhering to ergonomic principles, allowing users to engage with the smart mirror in a natural and comfortable manner.

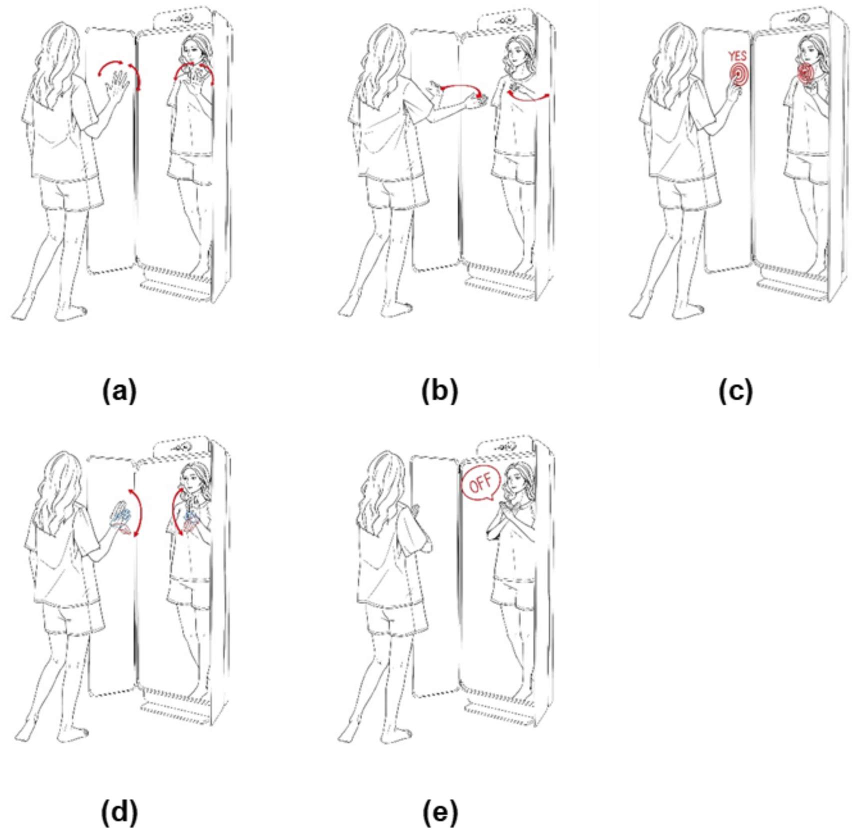


Fig. 15. Interaction Gesture Design: (a) Wake-up gesture; (b) Switch gesture; (c) Confirm or selection gesture; (d) Page scrolling gesture; (e) End or close gesture.

Physical Structure Design of the FBS-Based Smart Wooden Dressing Mirror

The hardware architecture of the smart dressing mirror comprises five primary components: the display module, mirror module, lighting module, camera module, and support frame module.

The system integrates multiple modules into a cohesive functional unit. The central display module consists of a high-resolution OLED screen located behind the main mirror, accurately rendering clothing colors and textures while featuring a touch interface for intuitive navigation and seamless adjustment of virtual try-on scenarios. Adjustable lighting elements surrounding the display simulate different ambient lighting conditions, ensuring visual consistency of virtual garments. Two auxiliary mirrors are hinged to the sides of the display *via* 3/4 circular plastic pivots, allowing flexible angle adjustments; they can fold inward during storage or transport to protect the display surface and reduce mechanical damage, while providing multi-angle viewing during use. The camera module incorporates multiple large-aperture, high-resolution lenses for full-body scanning and dimensional measurement, generating precise virtual body models from multi-angle data capture; cameras can retract when not in use to enhance privacy and reduce impact risk. The support frame is crafted from high-quality solid wood and employs traditional mortise-and-tenon joinery to ensure structural stability and aesthetic appeal. The base connects to the main mirror *via* mortise-and-tenon joints and integrates a sliding rail mechanism, extending during use to maximize stability and retracting into the mirror for compact storage and transport. Through modular design and precise structural connections, the system achieves mechanical stability, functional integration, and reliable operation in typical indoor environments (Fig. 16). The integrated design eliminates the risks of connection failure and interfacial stress concentration that typically occur when an independent mirror unit is retrofitted, embedded, or assembled with heterogeneous materials (such as wardrobe substrates or door panels). The holistic structure has been optimized *via* mechanical simulation and weight-distribution alignment, ensuring a more uniform stress distribution and effectively preventing potential hazards such as falling, loosening, or fatigue failure induced by improper subsequent manual installation.

The smart dressing mirror adopts a minimalist and contemporary design that aligns with modern home aesthetics. Its structure is divided into multiple sections: the central main mirror incorporates a high-definition OLED display, flanked by two standard high-definition side mirrors.

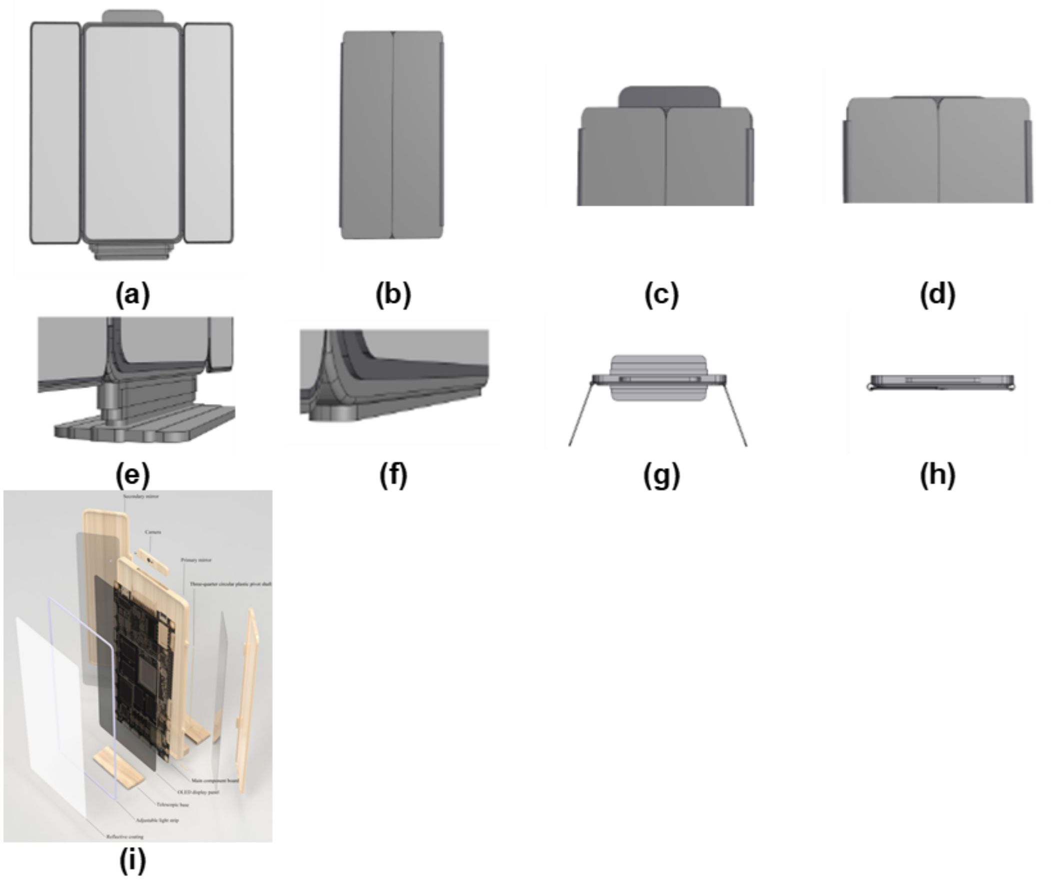


Fig. 16. Hardware architecture planning of the smart dressing mirror based on the FBS model**:** (a) Front view of the mirror in fully unfolded state; (b) Front view of the mirror in fully folded state; (c) Camera module in active mode; (d) Camera module in standby mode; (e) Telescopic stand fully extended; (f) Telescopic stand fully retracted; (g) Top view of the mirror in unfolded state;(h) Top view of the mirror in folded state**;** (i) Structural Diagram of the Dressing

A ring of adjustable light strips surrounds the main display to provide flexible illumination, while the upper section houses a retractable camera module and the lower section integrates a telescopic support frame. In terms of material and structural design, the main body housing the electronic components utilizes a composite structure that combines an aluminum alloy frame with wood veneer. This approach preserves the visual texture and tactile perception of wood while enhancing the structural stability, safety, and manufacturability of the product compared with a conventional solid wood structure. Compared with aluminum or other metal alternatives, wood provides superior tactile warmth and a more inviting, natural aesthetic, avoiding the cold, impersonal feel often associated with purely metallic smart household products. This combination of structural robustness, ergonomic comfort, and visual warmth ensures a functional yet aesthetically pleasing product (Fig. 17).

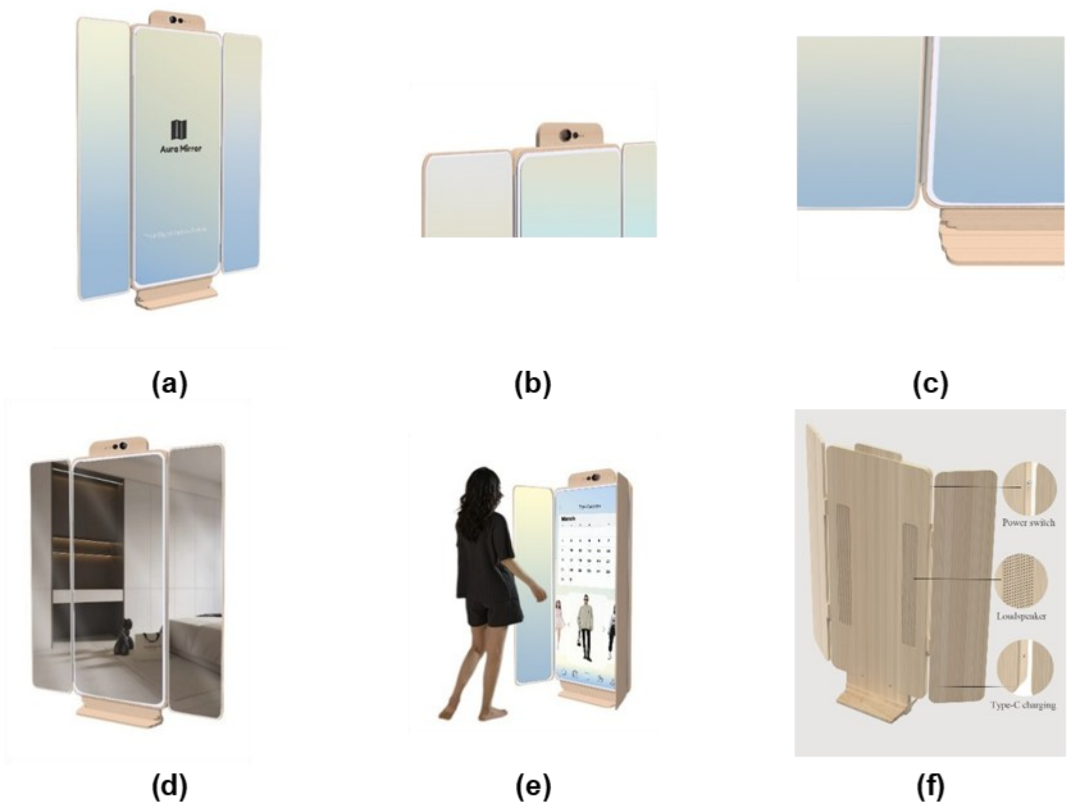


Fig. 17. Intelligent dressing mirror appearance design. (a) Product appearance; (b) Camera module details; (c) Edge details of the mirror; (d) Usage scenarios; (e) Companion app usage scenarios; (f) Schematic diagram of the rear view of the dressing mirror

Potential User Evaluation

The evaluation of the proposed design scheme was conducted through the online survey platform Wenjuanxing, targeting a group of potential users. A total of 93 valid questionnaires were collected (Fig. 18). The questionnaire was developed based on a seven-point Likert scale and comprised 16 items, quantitatively assessing the design across four core dimensions: purchase intention (Q1-Q4), perceived usefulness (Q5-Q8), interactivity (Q9-Q12), and innovativeness (Q13-Q16). SPSS analysis indicated that the overall Cronbach's alpha coefficients for the questionnaire were all above 0.8, demonstrating good internal consistency and reliability. The scoring intervals were categorized into three levels: 1-3 as "dissatisfied" (negative evaluation), 4 as "basically satisfied" (neutral or average evaluation), and 5-7 as "satisfied," with scores above 6.0 classified as "very satisfied."

Based on the distribution of mean scores across the 16 items from the 93 valid responses, the averages for purchase intention, perceived usefulness, interactivity, and innovativeness were concentrated within a narrow range of 5.913 to 6.3043, indicating generally high evaluations. Specifically, the purchase intention dimension (Q1-Q4) ranged from 5.913 (Q2) to 6.1957 (Q4). The perceived usefulness dimension (Q5-Q8) scored between 6.0761 (Q6) and 6.2935 (Q8). In the interactivity dimension (Q9-Q12), Q12 received the highest overall score of 6.3043, while Q10 recorded the lowest within the dimension at 6.0217. The innovativeness dimension (Q13-Q16) fluctuated between 5.9565 (Q14) and 6.2283 (Q16). Statistical analysis revealed that the proposed design performs exceptionally well on the seven-point scale, with mean scores across all four dimensions falling within the "very satisfied" range. Among them, innovativeness achieved the highest overall score, significantly surpassing the other dimensions, suggesting strong novelty in visual language, functional logic, and interaction concepts. Purchase intention and interactivity followed closely, indicating considerable market attractiveness. Although perceived usefulness received comparatively lower scores, it still remained at an excellent level. The core strength of the proposal lies in the strong association between high innovativeness and high purchase intention, reflecting the design's aesthetic and conceptual advancement. The primary shortcoming is a slight gap between functional practicality and formal novelty. In response to these findings, future iterations will focus on maintaining the existing innovative visual identity while further streamlining interaction steps and reducing users' cognitive load, thereby facilitating a comprehensive transition from "conceptual innovation" to a closed-loop experiential system.

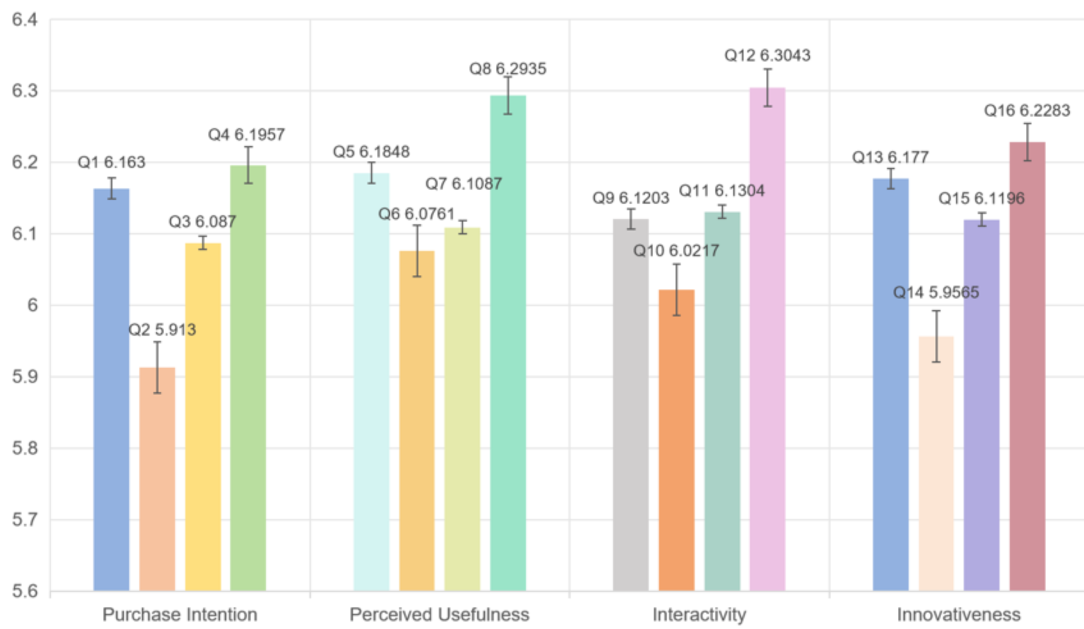


Fig. 18. Average scores of potential users on the four dimensions of the design proposal

DISCUSSION

Interpretation of Findings

The Kano-model analysis reveals that users' expectations toward smart wooden dressing mirrors are no longer limited to basic functional realization, but increasingly they emphasize emotional interaction, immersive experience, and intelligent lifestyle integration. The dominance of Attractive (A) attributes indicates that users place significant value on innovative and emotionally engaging functions capable of generating surprise, entertainment, and psychological companionship. Features such as Virtual Try-on, Multi-scenario Simulation, Ethnic/Holiday-themed Outfit Simulation, and Fashion Trend Updates achieved relatively high Better coefficients and sensitivity values, demonstrating that emotionally driven and experience-oriented functions play a critical role in enhancing user satisfaction and strengthening product attractiveness. This finding suggests that contemporary smart furniture design is gradually shifting from purely utilitarian functionality toward experiential and affective interaction.

Among all attributes, Virtual Try-on exhibited the highest sensitivity coefficient, indicating that users regard immersive visual interaction as one of the most influential aspects of intelligent dressing-mirror experiences. This reflects the increasing demand for personalized digital aesthetics and interactive consumption scenarios among young adults living alone. Similarly, Multi-scenario Simulation and themed outfit recommendation functions further demonstrate users' preference for situational guidance and emotionally resonant dressing experiences. These results imply that future smart furniture systems should not merely serve as functional tools, but should evolve into interactive lifestyle companions capable of supporting emotional engagement and self-expression.

The analysis also identified several One-dimensional (O) attributes, including Companion Mobile App, Lightweight Device Design, Modular Design, and Hidden Camera functionality. These attributes directly influence user satisfaction in a linear manner, meaning that better performance leads to higher satisfaction, while poor performance results in immediate dissatisfaction. Notably, the Companion Mobile App showed the strongest negative Worse coefficient, indicating that users are highly sensitive to deficiencies in system connectivity and interaction continuity. This finding highlights the importance of maintaining stable cross-device interaction and seamless digital ecosystems in smart furniture design.

In addition, Easy-to-Transport Structure, Simple Appearance, and User Privacy Protection were classified as Must-be (M) attributes. Their classification demonstrates that users consider these features as fundamental prerequisites rather than sources of delight. In particular, privacy protection reflects users' growing concerns regarding intelligent sensing technologies and data security within domestic environments. This suggests that smart furniture products must establish trust and perceived safety before advanced intelligent functions can effectively generate positive user experiences.

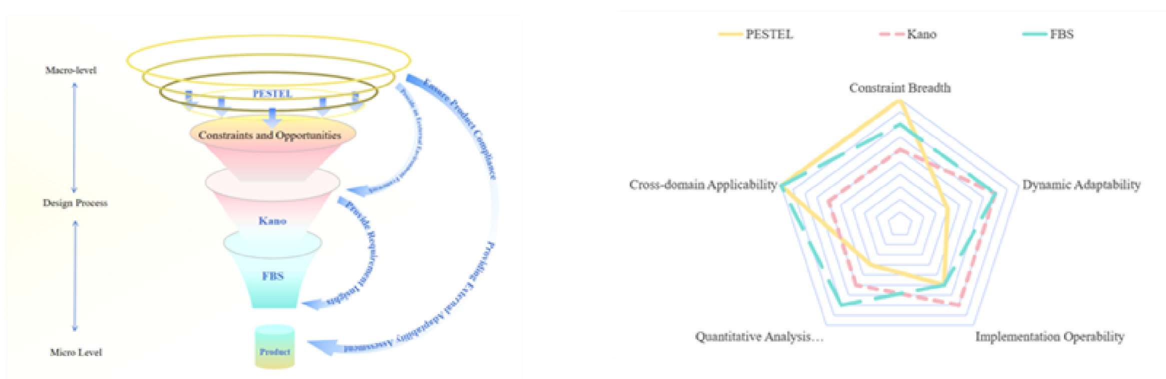
Overall, the findings indicate that the design value of smart wooden dressing mirrors lies not only in technological integration, but also in the creation of emotionally engaging, aesthetically immersive, and psychologically supportive user experiences. The Kano-based requirement analysis therefore provides an important empirical foundation for subsequent functional prioritization, interaction optimization, and conceptual development within the FBS-driven smart furniture design framework.

Comparison with Previous Studies

Previous studies on smart furniture have mainly focused on technological implementation, functional optimization, or market feasibility, while macro-environmental analysis tools such as PESTEL are often used only as descriptive background frameworks. As a result, user requirement analysis and product design decisions are frequently disconnected. Compared with previous studies, this research has integrated the PESTEL, Kano, and FBS models to establish a progressive macro–meso–micro analytical pathway. The study systematically translates macro-level contextual constraints into structured user requirements and further into concrete design parameters, thereby forming a closed-loop design logic from policy context to product implementation (Fig. 19).

Existing Kano-based studies generally treat user preferences as isolated variables under stable market conditions. In contrast, this study has incorporated policy regulation, privacy concerns, and digital lifestyle trends into the demand evaluation process, thereby enabling user requirements to be dynamically interpreted within broader socio-technical contexts. In addition, previous FBS-related studies mainly emphasize conceptual modeling and functional decomposition, whereas this study further embeds environmental constraints and user-demand data into the behavioral and structural transformation process. Consequently, product functions are derived not only from designer intuition, but also from real-world contextual constraints and user requirement analysis.

Another distinction lies in the study's emotional and experiential orientation. Traditional smart furniture research often prioritizes technological intelligence and operational efficiency, whereas this study has emphasized emotional companionship, immersive interaction, and experiential resonance among young adults living alone, reflecting the transition of smart furniture design from functional utility toward affective experience construction.



(a) (b)

Fig. 19. (a) Logical diagram of the framework structure; (b) Comparative chart of model capabilities

Theoretical Implications

This study has contributed to the theoretical development of smart furniture design research by constructing an integrated analytical framework that combines the PESTEL model, Kano model, and FBS model. Unlike conventional studies that separately examine macro-environmental factors, user requirements, and product functions, this research has established a progressive macro–meso–micro transformation logic, enabling external socio-technical constraints to be systematically translated into actionable design parameters. This framework expands the application boundary of traditional design-decision models and provides a more structured methodological pathway for intelligent product innovation research.

This study has introduced emotional experience and socio-cultural context into smart furniture requirement analysis, shifting the focus of intelligent furniture research from purely functional utility toward affective interaction and experiential value construction. By emphasizing emotional companionship, immersive interaction, and personalized experience among young adults living alone, the research enriches the theoretical understanding of user-centered intelligent furniture design under contemporary digital lifestyles.

Limitations

Despite the methodological and design framework innovations presented in this study, certain limitations need to be acknowledged. First, the empirical data were collected from a specific region and demographic, namely urban youth in Fuzhou. This group generally possesses relatively high digital literacy, frequent engagement with mobile platforms, and greater exposure to smart home technologies. Therefore, the findings of this study cannot be generalized to all regions or populations. The proposed PESTEL-Kano-FBS integrated framework, however, exhibits strong contextual adaptability and transferability at the methodological level. By treating macro-level constraints as variable input conditions rather than fixed premises, the framework can be adjusted according to different socio-cultural, policy, regulatory, and technological environments. Consequently, the generalizability of this study primarily lies in its methodological and design logic, rather than in the direct replication of specific empirical results. Future research could apply this framework to different regions and populations to expand its potential for context-sensitive design innovation.

Future Work

This study has been design-methodology oriented. The smart dressing mirror and its functional configurations proposed herein remain at the conceptual design and strategic level. The primary purpose is to explore how macro-contextual constraints and user demand structures can be systematically translated into actionable design parameters. Future research could build on this foundation to further develop functional prototypes, validate and refine the proposed design solutions and methodological framework through context-specific user testing and long-term usage data, thereby advancing the research outcomes from conceptual exploration toward practical application.

CONCLUSIONS

1. The unique attributes of wood have long made it a core material in household design, but traditional wooden designs can no longer meet the growing demands for intelligent and emotionally responsive living environments. Therefore, this study explored an intelligent optimization pathway for the personalized design of wooden dressing mirrors. This study proposed and validated an integrated PESTEL-Kano-FBS framework to guide the intelligent enhancement of wooden household products, addressing the personalized needs of young adults living alone in smart home product

design. The empirical results provided robust statistical support for the framework's reliability and validity. Specifically, the Kano questionnaire demonstrated excellent psychometric properties (KMO > 0.92, Bartlett's test of sphericity $p < 0.001$, Cronbach's $\alpha > 0.92$). Among 17 identified user requirements, the analysis classified them into 3 Must-be (M), 4 One-dimensional (O), 9 Attractive (A), and 1 Indifferent (I) attribute. "Virtual try-on" emerged as the most influential Attractive attribute with the highest satisfaction sensitivity coefficient (0.734), followed by "multi-scenario simulation" (0.692) and "style recommendation" (0.657), reflecting users' strong preference for immersive and adaptive product experiences.

2. Building on these insights, the FBS-based design translation effectively mapped user requirements to corresponding product functions, behaviors, and structures. The process guided the creation of a modular, foldable, and interactive smart dressing mirror, demonstrating a coherent linkage between user expectations and technical realizations. This design not only enhanced functional adaptability but also embodied emotional and aesthetic dimensions valued by young single users in compact living spaces. Notably, the study focused on wooden household products, introduced intelligent modules into the traditional wooden dressing mirror. This enhancement allows the mirror to meet the growing demand for smart, interactive functionalities while preserving the warmth, tactile comfort, and aesthetic appeal inherent in wood.
3. This research contributes to design science by establishing a systematic methodological pathway that bridges macro-environmental analysis, user requirement quantification, and conceptual design translation. By extending the traditional Kano-FBS model from theoretical abstraction to practical product realization, the study provides empirical validation and operational guidance for user-centered smart product innovation. The proposed framework also offers potential for broader applications in sustainable and personalized product development domains.

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Use of Generative AI

During the preparation of this work, the authors used ChatGPT to assist in improving the clarity and fluency of the language. After using this tool, the authors carefully reviewed and revised the text as necessary, and take full responsibility for the content of the publication.

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APPENDIX

Table S1. Questionnaire on the Demand of Solitary Youth for Smart Dressing Mirrors

Demographic questions		
01	Your age range:	●18-22 ●23-27 ●28-31 ●32-35
02	How long have you been living alone?	●Less than 6 months ●6-12 months ●1-3 years ●More than 3 years

<table>
<tr><th colspan="3">Functional Needs of Smart Dressing Mirrors</th></tr>
<tr><td>01</td><td>Virtual try-on</td><td rowspan="17">For each of the following potential functions, please indicate your attitude both if the function is available and if the function is not available, using the following five-point scale:
1=Strongly dislike
2=Dislike
3=Neutral
4=Like
5=Strongly like</td></tr>
<tr><td>02</td><td>Style recommendation</td></tr>
<tr><td>03</td><td>Integration with major e-commerce platforms (purchase links)</td></tr>
<tr><td>04</td><td>Mobile App control</td></tr>
<tr><td>05</td><td>Gesture/voice control</td></tr>
<tr><td>06</td><td>Multi-scenario simulation (e.g., office, street, classroom)</td></tr>
<tr><td>07</td><td>Social interaction (sharing outfit dynamics in a virtual community)</td></tr>
<tr><td>08</td><td>Gamification experience (ranking lists for outfit sharing, etc.)</td></tr>
<tr><td>09</td><td>Lightweight design</td></tr>
<tr><td>10</td><td>Multi-purpose extensions (e.g., weather forecast, health monitoring)</td></tr>
<tr><td>11</td><td>Ethnic costumes and holiday-themed outfit simulation</td></tr>
<tr><td>12</td><td>Fashion news and trend updates</td></tr>
<tr><td>13</td><td>Easy transportation and portability</td></tr>
<tr><td>14</td><td>Streamlined and minimalist appearance</td></tr>
<tr><td>15</td><td>Modular design (e.g., stands, wheels as optional add-ons)</td></tr>
<tr><td>16</td><td>User data privacy protection (e.g., storage card, one-click formatting)</td></tr>
<tr><td>17</td><td>Hidden camera design (visible when in use, concealed or physically covered when not in use)</td></tr>
</table>

Open-Ended Question
Please describe your ideal VR try-on scenario (e.g., body scanning, fabric fitting, different lighting environments, etc.).

Table S2. Questionnaire on the Questionnaire on Potential Users' Evaluation of the Smart Dressing Mirror Design Proposal

01	I would like to purchase this product.	1=Strongly Disagree 2=Disagree 3=Somewhat Disagree 4=Neutral 5=Somewhat Agree 6=Agree 7=Strongly Agree
02	I would recommend this product to people around me.	
03	I am willing to pay a premium for the design of this product.	
04	This product would be my first choice among similar options.	
05	This product can effectively solve the practical problems I encounter.	
06	The functions provided by the product are highly practical.	
07	Using this product can improve my efficiency in relevant scenarios.	
08	The core value of this product meets my essential needs.	
09	The operation logic of the product is clear and easy to understand.	
10	I can get started with the product's functions quickly without complex learning.	
11	The feedback during interaction is timely and intuitive.	
12	The overall interface or physical interaction feels smooth and natural.	
13	The design concept of this product is very unique and novel.	
14	Compared to existing products, this design has significant breakthroughs.	
15	The visual style of the product brings a refreshing aesthetic experience.	
16	The product applies innovative technologies or materials creatively.	