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EVALUATION METHOD FOR INTELLIGENT KITCHEN DESIGN BASED ON FBS/AHP

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Abstract. *Purpose:* To improve the deficiencies in the current design process of intelligent domestic kitchens, focusing on user research and design evaluation, this paper aims to enhance kitchen work efficiency and comfort, elevate users' emotional experience of kitchen life quality, expand the functionality of smart kitchen furniture and optimize the elements of intelligent kitchen design. *Method*: Grounded in user interviews and observation, this study incorporates the Function-Behavior-Structure (FBS) model and the Analytic Hierarchy Process (AHP) method. Initially, user behaviors and pain points are identified through interviews and observations. Subsequently, utilizing the FBS model's "Function-Behavior-Structure" mapping, the essential elements of the intelligent domestic kitchens for implementing functions are determined. Finally, the AHP method is employed for a comprehensive evaluation of the discovered functional innovations and system elements, establishing their weight distribution. *Results:* The integration of FBS and AHP in innovative design evaluation, through the analysis of behavioral pain points, requirement exploration and the process of functional innovation and system element determination, has applied the FBS and AHP design evaluation methods to the demand analysis process of intelligent kitchen design, which enhances the objectivity of decision making of intelligent design, user experience, function design and versatility. *Conclusion*: This method demonstrates practicality in intelligent domestic kitchens design, providing new perspectives and references for the evaluation strategy of domestic kitchens design.

Keywords: *AHP, evaluation method, FBS, intelligent, kitchen design.*

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1. Introduction

With the development of technology and the improvement of living standards, people are increasingly focusing on the household kitchen living space. As the place is related to users' three meals a day, the quality of kitchen furniture impacts the relationships among family members (Zainal Abidin *et al*., 2021). Many scholars both domestically and internationally have researched kitchen home environments, aiming to enhance kitchen work efficiency and comfort, reduce monotony and fatigue and create higher spatial utility value and user activity quality. Simultaneously, they strengthen collaboration and communication among family members, contributing to the creation of positive experiential value and human care in family life (Ismail *et al*., 2021; Mihalache *et al*., 2022).

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On the other hand, with the development of the Internet of Things (IoT) and artificial intelligence (AI) technology, the design of smart homes is gradually becoming widespread. The concept of the intelligent kitchen was introduced by the German company, HeidiTech, in the early 21st century and it was registered as an independent trademark. Its goal is to achieve intelligent innovation within the components of kitchen furniture, coordinating with smart home appliances. This aims to design various kitchen functions to be more user-friendly, making it easier, more efficient and interactive for users. In terms of basic components, the intelligent kitchen consists of kitchen furniture, appliances and physical space. From a systemic perspective, the intelligent kitchen is a smart dining and cooking service system, that aims to provide clean, comfortable, safe, healthy, efficient and user-friendly services for family dining and cooking activities (Balaji *et al*., 2020). HeidiTech summarizes the concept of the intelligent kitchen as shortening operation distance, optimizing operation processes, clear functional planning and rational spatial layout. Many scholars have also conducted research on intelligent kitchens from various perspectives, including smart fridges, smart stoves, smart kitchen cabinets, automation and monitoring (Toyong *et al*., 2021; Yu & Sung, 2023). The trend towards intelligent kitchens is expected to be an inevitable direction for future kitchens.

Despite the progress made in the domestic and international design and application of smart kitchens, most scholars have focused on individual smart products. There is still a lack of comprehensive evaluation of system elements in smart kitchen design. This study addresses this gap by using the FBS model and AHP method to assess these elements. The aim is to improve deficiencies in the current design process of intelligent domestic kitchens, focusing on user research and design evaluation. This includes enhancing kitchen work efficiency and comfort, elevating users' emotional experience of kitchen life quality, expanding the functionality of intelligent kitchen furniture and optimizing the elements of intelligent kitchen.

2. Research method

2.1. User Interviews and Observations

This study adopts interview and observation methods. A total of 10 kitchen users are selected, including three novice users, four regular users and three experienced users. The basic information of users participating in the survey is shown in Table 1.

The in-depth interview lasted for 20-30 minutes, mainly focused on their daily kitchen furniture use scenarios and centered on users' kitchen activity habits. Specific to the storage space, staple food storage, fresh food storage, condiment storage, refrigerator, pot storage, tableware storage, sink, washing supplies, garbage cans, operating countertops, kitchen appliances, oil smoke problems, stove problems, regional planning and operation of the operating line as a structure to understand the user's kitchen activities in the pain points. To get specific information on kitchen furniture design strategies.

The whole process of the implementation of the observation method was carried out at the user's home. The researchers observed and photographed the kitchen activities of each sample during kitchen cooking and post-meal preparation and recorded them using the observation frame table. The total cooking and post-meal preparation time of each sample is about 50min to 70min and the cooking activities are all completed by the kitchen users independently. The types of dishes are determined by the kitchen users according to their daily dining habits and the researchers will recommend the users to choose dishes with low cooking difficulty. According to the user operation process, the whole recording process is divided into three stages: pre-cooking, cooking and post-meal sorting. Based on the information obtained from interview and observation, the user behavior recording is shown in Table 2.

Table 1. Basic information of users

User	Age	Gender	Occupation	Cooking Frequency	User Type	Kitchen Type	Picture
User 1	26	Female	Sales	1-2 times per week	Novice	U-shape	
User 2	25	Female	Bank Clerk	2-3 times per week	Novice	L-shape	
User 3	26	Female	University Counselor	2-3 times per week	Novice	single row-shape	
User 4	35	Female	Sales Manager	3-4 days per week	Regular	L-shape	
User 5	33	Female	Accountant	5-6 days a week	Regular	U-shape	
User 6	36	Female	Middle School Teacher	5-6 days per week	Regular	U-shape	
User 7	38	Female	University Teacher	4-5 days per week	Regular	L-shape	
User 8	50	Male	Manager	Cooks daily	experienced	U-shape	
User 9	55	Female	Retired Teacher	Cooks daily	experienced	L-shape	

User 10	48	Female	Freelancer	Cooks daily	experienced	U-shape	

Based on the research, the cooking process is divided into Before Cooking, Cooking and After Cooking. The operations associated with these stages involve kitchen furniture products such as countertops, refrigerators, cabinets, sinks, stoves, rice cookers, microwaves, ovens, cooking tools and utensils, tableware and trash bins. Among these, the main pain points include ingredients expiring before cooking, difficulty in selecting dishes, lack of side dishes before cooking; during cooking, issues like forgetting to turn off the heat, boredom during waiting times, long preparation times and chaos when preparing multiple dishes simultaneously; after cooking, there are multiple trips between the dining and kitchen areas, challenges in storing leftover food, sink blockages, difficulty in waste sorting and water stains on kitchen utensils after cleaning.

Table 2. User behavior records

Stage	Item	Region	Behavior Analysis
Before	Decision	Random	The food type of the previous meal will affect the next food decision.
	Buy	Market	Pay more attention to the quality, freshness and price of food.
Cooking	Pre-processing	Preparation area	It makes the kitchen space more chaotic. The space of the operating area and the storage of various operating utensils are the key.
	Cooking	Cooking area	Users pay attention to the cooking time; the overlapping of the operation processes and the messy countertop make the operation difficult.
After	Dining	Dining area	Users make multiple trips between the cooking area and the dining area and pay attention to the placement of dishes and the method of keeping them warm.
	Cleaning	Washing & storage area	Cleaning is a very painful point for users, involving leftover disposal, kitchen waste classification, tableware cleaning, and storage.

2.2. FBS Model

The FBS model, proposed by Gero and Kannengiesser (2004), is used to analyze the design process (Kan & Gero, 2022). This model primarily achieves a comprehensive and rigorous hierarchical and modular analysis of complex systems through the mapping of functions, behaviors and structures. The introduction of behavior is used to describe the actions performed to fulfill functions, forming a dual mapping process of “function-behavior” and “behavior-structure”, providing a bridge for reasoning between functions and structures. Among the three variables in the FBS model, the function is a specific description of what a product system can do, representing the description of behavioral goals. Behavior is an analysis of the behavior process that occurs when users use the product’s functionality and represent the specific operations to achieve the functions. Structure refers to the product’s structure and the system’s solution is derived from the structure requirements obtained through behavior mapping, serving as the support for behavior (Gero & Milovanovic, 2021). Therefore, in the process of using the FBS model for design deduction, the function corresponds to the expected behavior of performing that function and the expected behavior corresponds to the selection and combination of structures used.

Currently, the FBS model has been widely applied in various design fields. Research based on the FBS model adopts a top-down product concept design analysis model (Wang *et al*., 2024), where function corresponds to design goals, behavior corresponds to the user's behavior process when using the product and structure corresponds to the design scheme of intelligent domestic kitchens, facilitating the mapping transformation to fulfill design requirements. The decomposition of the intelligent kitchen design based on the FBS model is illustrated in Figure 1.

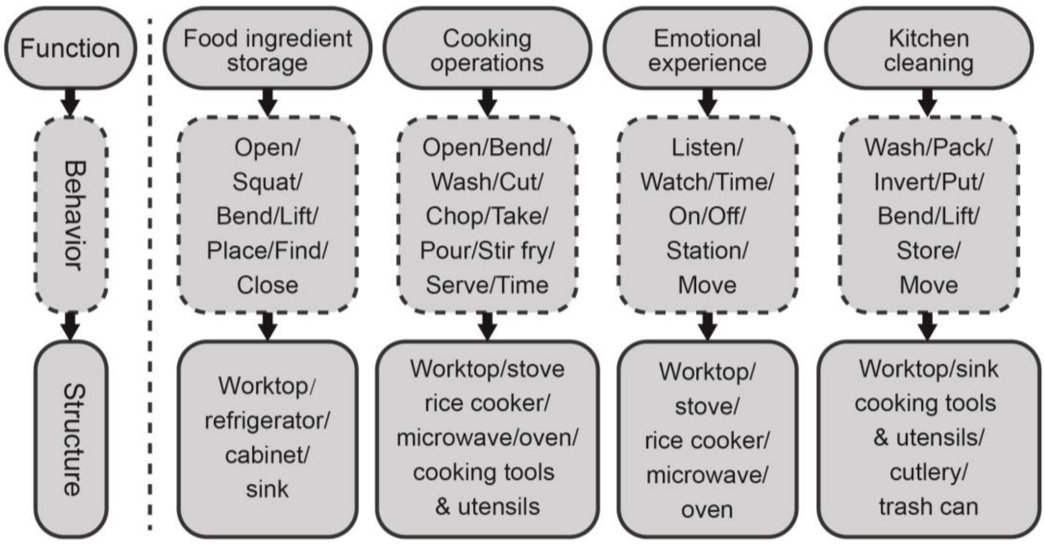

Figure 1. FBS model mapping diagram
Source: Drawn by the author

2.3. Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a systematic analysis method proposed by Saaty (1990) in the 1970s, combining qualitative and quantitative aspects. This method constructs a hierarchical model, treating complex multi-criteria decision-making problems as a whole and breaking them down into various components. These components are analyzed and decomposed into multiple criteria and constraints based on their internal relationships, forming a hierarchical structure with levels such as the goal level, criteria level and indicator level. Through qualitative and quantitative analysis calculations using a data model, an ordered hierarchical structure is formed to obtain the importance ranking among the factors. In recent years, many scholars have improved the algorithms of AHP (Ishizaka *et al*., 2012). Currently, its mainstream steps can be summarized in four stages:

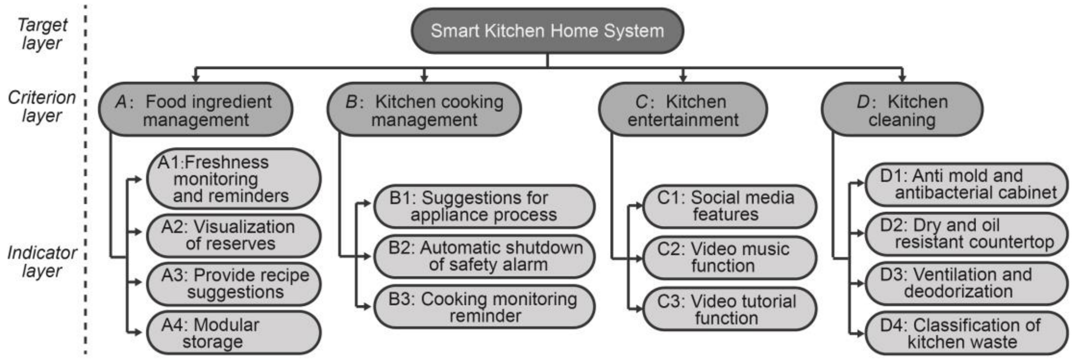

Figure 2. Intelligent Kitchen AHP Model
Source: Drawn by the author

2.3.1. Establish hierarchical structure model

Based on user interview information and the decomposition of the intelligent kitchen system derived from the FBS model, we delineate the four criteria at the goal level for user requirements in intelligent domestic kitchens. This encompasses a total of 14 corresponding indicators, each coded separately, as depicted in Figure 2.

2.3.2. Form judgment matrices

Combining pairwise comparison method, using a 9-point ratio scale, quantify the preferences of industry experts to form the criterion layer judgment matrix CL′ and four indicator layers judgment matrix A′, B′, C′, D′. This is to effectively assess the important relationships between various elements of user requirements. Five experts (three industrial designers, one interior designer and one chef) were invited to participate in the discussion on the importance of user requirements. The expert group uses the Delphi method (Green *et al*., 2007) to score pairwise comparisons of elements in the criteria and indicator layers, constructing the importance relationship judgment matrix $X_k = (a_{ij})n \times n$, where $a_{ij} = 1/a_{ji}$, $k = CL', A', B', C', D'$.

2.3.3. Weight values calculation and consistency checks

The geometric mean method is used to calculate the weight values of various factors in all layers and a basic consistency test is performed on matrix X_k. The specific calculation steps are as follows:

2.3.3.1. Normalize the elements in matrix X_k by column

$$\bar{a}_{ij} = {a_{ij}}\Big/{\sum_{k=1}^{q} a_{kj}}, \qquad (i, j = 1,2, \dots, n) \tag{1}$$

2.3.3.2. Summing up the normalized matrix along each row and dividing by the order n yields the weight values for each factor

$$\omega_i = \frac{\widetilde{\omega}_i}{n} = \frac{1}{n}\sum_{j=1}^{n} \bar{a}_{ij} \qquad (i, j = 1,2, \dots, n) \tag{2}$$

2.3.3.3. Calculate the maximum eigenvalue

$$\lambda_{max} = \frac{1}{2}\sum_{i=1}^{n}\frac{(x_k\omega)_i}{\omega_i} \tag{3}$$

where, w is the weight vector, $w = (w_1, w_2, \dots, w_n)$, $(x_k w)_i$ is the ith component of vector $x_k w$.

2.3.3.4. Consistency check

To ensure the effectiveness and rationality of the weight results, the consistency ratio (CR) is introduced to test the consistency of the judgment matrix, as follows:

$$CR = CI/RI \tag{4}$$

where $CI = \lambda_{max} - n/n - 1$, n is the order of judgment matrix. For $n = 3, 4, \dots, 9$ the values of RI are shown in Table 3. When CR < 0.1, it indicates that there are no logical errors in the judgment matrix and the weight results are considered reasonable and effective.

Table 3. RI value

Order n	*3*	*4*	*5*	*6*	*7*	*8*	*9*
RI	0.52	0.89	1.12	1.26	1.36	1.41	1.46

3. Result and analysis

3.1. Calculation of judgment matrix and weight values

Utilizing Formula (1), the judgment matrices of the criteria layer and indicator layer obtained from the five experts are normalized. Through Formula (2), the weight values of various factors in the normalized matrix are calculated. The calculation results of each weight value Wi of the criterion layer judgment matrix CL′ and four indicator layers judgment matrix A′, B′, C′, D′ are presented in Tables 4-8.

Table 4. CL′ Judgment matrix and weight values

CL′	*A*	*B*	*C*	*D*	W_i
A	1.0000	0.5000	5.0000	3.0000	0.3302
B	2.0000	1.0000	6.0000	2.0000	0.4358
C	0.2000	0.1667	1.0000	0.3333	0.0632
D	0.3333	0.5000	3.0000	1.0000	0.1708

Table 5. A′ Judgment matrix and weight values

A′	*A1*	*A2*	*A3*	*A4*	W_i
A1	1.0000	3.0000	5.0000	1.0000	0.4042
A2	0.3333	1.0000	3.0000	0.5000	0.1755
A3	0.2000	0.3333	1.0000	0.2500	0.0749
A4	1.0000	2.0000	4.0000	1.0000	0.3455

Table 6. B′ Judgment matrix and weight values

B′	*B1*	*B2*	*B3*	W_i
B1	1.0000	0.2000	0.3333	0.1096
B2	5.0000	1.0000	2.0000	0.5813
B3	3.0000	0.5000	1.0000	0.3092

Table 7. C′ Judgment matrix and weight values

C′	*C1*	*C2*	*C3*	W_i
C1	1.0000	1.0000	0.5000	0.2409
C2	1.0000	1.0000	0.3333	0.2106
C3	2.0000	3.0000	1.0000	0.5485

Table 8. D′ Judgment matrix and weight values

D′	*D1*	*D2*	*D3*	*D4*	W_i
D1	1.0000	0.3333	2.0000	1.0000	0.2020
D2	3.0000	1.0000	3.0000	2.0000	0.4566
D3	0.5000	0.3333	1.0000	0.5000	0.1202
D4	1.0000	0.5000	2.0000	1.0000	0.2212

3.2. Consistency test

Formula (3) is used to calculate the maximum eigenvalue of the judgment matrices for the criteria layer and indicator layer. Formula (4) is utilized to compute the CR value for consistency testing. The calculation results are shown in Table 9.

Table 9. Judgment matrices CR values

Item	*CL′*	*A′*	*B′*	*C′*	*D′*
λ_{max}	4.1158	4.0457	3.0037	3.0183	4.0458
CR	0.0434	0.0171	0.0036	0.0176	0.0172

After verification, the CR values of the judgment matrices for both the criteria layer and the indicator layer are below 0.1, demonstrating that there are no logical errors in the matrices and the weight results are considered reasonable and effective.

3.3. Analysis

The weight values of each element in the indicator layer are multiplied by the corresponding weight values in the criteria layer, obtaining the comprehensive weight values of each user demand element in the entire evaluation system. The ranking is as follows: Safety alarm and automatic extinguishing > Cooking monitoring and reminders > Freshness monitoring and reminders > Modular storage > Countertop drying and oil resistance > Visualized storage volume > Suggestions for small home appliance processes > Kitchen waste classification > Video tutorial functionality > Antimicrobial cabinet > Recipe suggestions > Ventilation and deodorization > Social media functionality > Video and music functionality, as shown in the Table 10.

Table 10. Comprehensive weight values and ranking

System elements	Code	Weight	Ranking
Freshness monitoring and reminders	A1	0.1335	3
Visualized storage volume	A2	0.0580	6
Recipe suggestions	A3	0.0247	11
Modular storage	A4	0.1141	4
Suggestions for small home appliance processes	B1	0.0478	7
Safety alarm and automatic extinguishing	B2	0.2533	1
Cooking monitoring and reminders	B3	0.1347	2
Social media functionality	C1	0.0152	13
Video and music functionality	C2	0.0133	14
Video tutorial functionality	C3	0.0347	9
Antimicrobial cabinet	D1	0.0345	10
Countertop drying and oil resistance	D2	0.0780	5
Ventilation and deodorization	D3	0.0205	12
Kitchen waste classification	D4	0.0378	8

For developers of intelligent kitchen, it is necessary to consider all the essential intelligent features at the beginning of development. However, for users, how to effectively obtain the information they want from the huge and complex intelligent kitchen system may become a new pain point. The researchers (Johare *et al*., 2022) describe the wonderful new possibilities of AI and iot in the intelligent home, where users can remotely access all kitchen automation features in the intelligent home, including security measures, energy and energy savings and timing Settings. The current intelligent kitchen implementation is mainly accomplished through wireless networks, smart phones and the Internet (Vu & Khanna, 2018). For users, the application of new technologies in the kitchen should minimize learning costs, so in the intelligent kitchen system, the information that users need to accept and want to get should have a higher priority. This research is based on the combination of FBS and AHP to explore how to objectively evaluate the needs of kitchen users.

Through the analysis combined with the calculated results of weighted sorting, it can be inferred that in formulating the design scheme for smart kitchen home appliances, attention should be paid to the following points: During research, user pain points were found to be mainly distributed in food management, cooking operations and kitchen cleaning and the smoothness of these three aspects will also affect users' emotional experience. It is noteworthy that compared to novice kitchen users, expert users may overlook more common pain points among novices and general users due to their improved skills or tolerance (Zainal Abidin *et al*., 2009). Therefore, during interviews and observational analysis, it is essential to distinguish between different user groups. The evaluation results show that kitchen cooking management is the most concerning functional element in smart kitchen home appliances for users, involving the safety attributes of the kitchen. Additionally, features such as freshness monitoring reminders in food storage and kitchen cleaning, along with countertop drying and oil resistance, are also focal points for users. These should be prioritized in the development of key functionalities during the design process.

4. Conclusions

The intelligent kitchen is a new field of research that improves the quality of life through the application of new technologies in life. Artificial intelligence (AI), data science (DS), machine learning (ML) or deep learning (DL) Internet of Things (IoT) and robotics concepts are being used to advance intelligent kitchens, playing a vital role in the home and catering industry. This research combines FBS and AHP, focusing on kitchen users, to study the design and evaluation methods of smart kitchen home appliances. Through in-depth interviews and observations of users, analyzing user behavior and identifying pain points, the FBS model is utilized to connect kitchen functions, user behavior and furniture carriers. The AHP method is employed to categorize specific functional indicators and a comprehensive evaluation of smart kitchen system elements is conducted through a combined subjective and objective approach.

The application of new technologies and new functions will undoubtedly bring learning costs to users. A large part of kitchen users are older and there are certain obstacles to the learning and acceptance of new technologies. The original intention of the development of smart kitchen is to improve the kitchen environment and the quality of life of users and the accurate assessment of user needs will help reduce user learning costs in the practice of smart kitchen and provide a better user experience. The study indicates that integrating the FBS model and AHP method for user research can effectively uncover user needs, enhance the objectivity and scientificity of system element evaluations and improve the efficiency of decision-making in the functional elements during the design process, which has certain reference significance for the function, interaction and user demand analysis in the interface design of smart home kitchens.

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