Analysis and Design of Household Intelligent Planting Products Based on Hall Three-Dimensional Structure

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Abstract. In this paper, Hall three-dimensional structure model has been applied in the design of household intelligent planting products. There are some shortcomings in the current household intelligent planting products, which can not well meet the needs of users, and the user experience needs to be improved. Therefore, in order to establish a complete design process of household intelligent planting products, optimize the design steps and improve the design efficiency, Hall three-dimensional structure theory is used as a guide in this study, and a design model of household intelligent planting products is proposed, which is composed of three dimensions: knowledge, time and logic. In general, this study is based on the guidance of Hall three-dimensional structure theory, and takes improving user interaction experience as the core, and Kano model and AHP as tools to carry out the design practice of household intelligent planting products. Finally, an intelligent planting product and matching software were proposed, which can help improve user experience and satisfaction in the planting process.

Keywords: Product design · Hall three-dimensional structure theory · Home environment · Intelligent planting · User evaluation

1 Introduction

With the development of urbanization and the increase of population density, the per capita green area decreases year by year. Urban residents' aesthetic and emotional needs for natural scenery have led to the rapid development of home gardening. The development of various cultivation techniques makes it possible to grow plants intelligently, which provides more convenient conditions for the construction of urban ecological civilization. Putting ornamental plants in the home environment has become the hobby of many people, and various ornamental plants have gradually are regarded as an important decorative element in the home environment. However, the existing household intelligent planting products in the market have been found to have some problems such as single shape and thin function, which bring certain difficulties for users to successfully complete the planting of plants. This paper aims to propose a standardized intelligent planting

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product design process based on hall three-dimensional structure theory and home environment. Through this process the designer can adjust the design work according to the orderly steps in time and complete the design task at a higher level.

2 System Engineering Methodology

Hall three-dimensional structure was proposed by A.D. Hall, an American systems engineering scholar, in 1969 to optimize systems engineering practice. It consists of three dimensions, namely time dimension, logic dimension and knowledge dimension, and its goal is to define work objectives to achieve optimal results [1].

Hall 3D structure model has been applied to the design of related products by many researchers, and some research results have been achieved. Zhang R et al. [2], by building a Hall three-dimensional structure model of the main furniture for growing children, transformed various design tasks into multiple nodes to achieve the design objectives in an orderly manner. Zheng Y et al. [3] used Hall three-dimensional structure for reference to conduct logical analysis and construction of the wearable intelligent products, making the design process proceed in an orderly manner and improving the design efficiency.

On the whole, Hall three-dimensional structure is a method to manage design logically and sequentially and solve problems integrally by summarizing all kinds of knowledge [4]. Therefore, this paper attempts to introduce the Hall three-dimensional structure into the design and development process of household intelligent planting products, so that the design process can be systematically promoted, the design level can be effectively improved.

3 Hall Three-Dimensional Structural Model of Household Intelligent Planting Products

3.1 Time Dimension

Firstly, the time dimension of the design project, which reflects the sequence of each design step in the design process, is established. The traditional Hall three-dimensional structure can be divided into seven stages from planning to updating in time dimension [1]. In this design project, considering that the design task involves the professional knowledge of plant planting and cultivation, and the final product is realized in the form of combination of software and hardware in the preliminary design conception, additional technical preparation and matching APP design stage are added to ensure the smooth development of the subsequent design. As a result, This design project is implemented in seven stages, including market and user survey, technical preparation, scheme design, scheme selection, matching APP design, product production and product update iteration.

3.2 Logical Dimension

Logical dimension refers to the system analysis thinking and design steps followed in each stage of the design process [5]. It is a dimension oriented by solving problems and guided by logical analysis. When constructing the logical dimension of this design project, it is divided into seven stages, which are design background investigation, clear design requirements, collection of design data, proposal of design scheme, evaluation of design scheme, implementation and update. Moreover, the logical dimension and the time dimension are consistent in development. For example, the time dimension develops from the stage of market and user research to the stage of technical preparation, and the logical dimension correspondingly presents the stage from clear design requirements to design data collection. However, in logic dimension, the design of the supporting APP is also included in the stage of design proposal, while the subsequent evaluation stage is to judge both the physical design and the design of the APP. The design of physical products and APP is sequential in time dimension, but parallel in logical dimension. Both dimensions end up with production and renewal.

3.3 Knowledge Dimension

The knowledge dimension is not linear as the logic dimension and the time dimension. It is called at any time according to the requirements of the work steps. It has the flexibility and comprehensiveness of technology application. Reasonable use of knowledge can ensure the rationality of design and production.

In this system, the knowledge dimension can be divided into two aspects: on the one hand, it is related to plant cultivation technology and knowledge, which has a strong professional nature, covering soilless cultivation technology, medium water and fertilizer monitoring technology, etc. This part of knowledge reserve needs to be realized through the technical preparation stage in the time dimension. On the other hand, it is related to the knowledge needed for the design work, such as engineering technology, social science and design theory. In these two parts, there is no direct connection between the knowledge points. All kinds of knowledge can be reasonably applied to each step under the guidance of Hall three-dimensional structure, and the whole design process can be ensured to complete in an orderly and efficient way.

4 Specific Design Process

4.1 Market and User Research

In the time dimension, the market and user research is the first stage of the design project. Market and user information is collected at this stage, which is then further analyzed and refined to obtain the overall design purpose. In the logical dimension, this step is divided into the investigation of design background and the definition of design requirements. Its significance is to point out the direction for the subsequent steps such as design proposal and design evaluation. In addition, this stage needs to be supported by user research and user psychological knowledge in the knowledge dimension, and at the same time, certain data processing ability is required to sort out and summarize the collected information.

First of all, several existing household intelligent planting products which are popular in the market are selected as comparison objects. The products' functions, loss of functions, other shortcomings, and technical rationale were compared.

The comparison details are shown in Table 1. It can be found that these products can provide basic functions to ensure plant growth to a certain extent, but at the same time, there are some functional deficiencies. The missing functions of each product are different. In order to clarify which functions are necessary, user evaluation will be carried out in the next step to summarize and rank the functions of household intelligent planting products.

Table 1. Comparison of existing products

Name	Function	Loss of function	Other shortcomings	Technology
Haier intelligent planting box	Simulate sunlight, provide soilless cultivation function	Monitor the growing environment	Not suitable for home environment modeling	Sunlight simulation, soilless cultivation
Xiaomi smart flower pot	Monitor soil moisture and fertilizer and alert on your mobile phone	Simulate sunlight	/	EC and pH sensing, Internet of Things
HuiU planter	Simulate sunlight and monitor illumination	Monitor soil moisture and fertilizer	Must be connected to the wired power supply, assembly trouble	Sunlight simulation, Internet of Things
iGrow intelligent brightening flowerpots	Simulate sunlight	Monitor soil moisture,fertilizer and illumination	/	Sunlight simulation

The user requirements are sorted through the Kano model. First, preliminary questionnaire survey, in-depth interview and other research methods are used to collect preliminary user survey data. The functional requirements of users are sorted out and summarized, as shown in Table 2.

Then, the requirements are classified and integrated through questionnaires combined with Kano model, and the better-worse coefficient is calculated according to the questionnaire results, indicating which functions can increase user satisfaction and which functions can reduce user satisfaction [6]. Accordingly, the classification results of user requirements are obtained, as shown in Fig. 1.

As can be seen from Fig. 1, the focus needs of users are mainly in the aspects of convenient planting of plants and embellishment of home environment. Since the cultivation of ornamental plants is a behavior with a more aesthetic nature, most users emphasize that the overall device can ensure the good growth of plants and at the same time have ornamental and aesthetic value. In a word, the follow-up design should firstly monitor the plant growth environment, provide light and moisture and other functions

Table 2. Scoring result

Number	Function	Number	Function
1	Easy to operate	11	Time-saving
2	Provide illumination	12	Noiseless
3	Provide water	13	Powerfrugal
4	Monitoring the growth environment	14	Small size
5	Monitor growth	15	Safe
6	Record growth	16	Allow replacement of plants
7	Appreciate the plant	17	Clean
8	Allow replacement of plants	18	Portable
9	Decorative interior space	19	Easy to maintenance
10	Remote control	20	Free switch

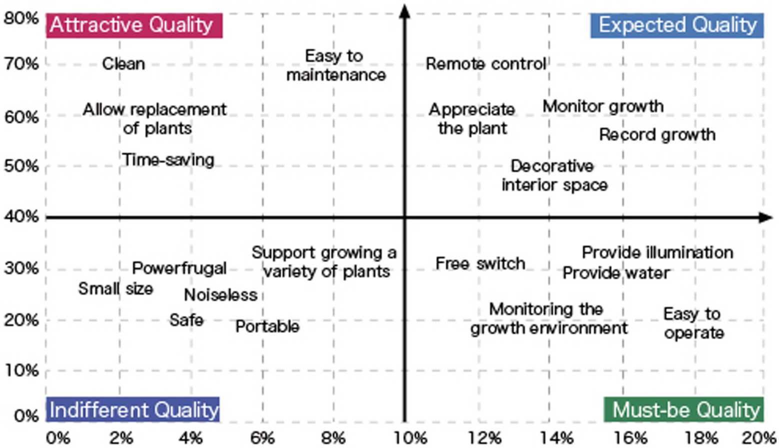

Fig. 1. Kano model of user requirements for the project

to conveniently complete plant planting and maintenance. Its adornment property and ornamental property is also considered to be a very important requirement.

Through the above analysis, the positioning and direction of the design can be clarified, and the design can be carried out in a targeted way, so that the user's acceptance and liking of the final design scheme will be improved.

4.2 Technical Analysis

Technical analysis is the second stage of the time dimension. Correspondingly, it is embodied in the third stage in the logical dimension, namely the collection of design data. In this stage, the information and data related to intelligent culture technology are collected and summarized, so as to ensure that the gaps in botanical knowledge in the knowledge dimension are filled. Without the data obtained from the technical analysis, the subsequent stages of the time dimension would not proceed smoothly. On the basis of these data, the technical feasibility of subsequent scheme design will be guaranteed in the logical dimension.

As can be seen from the literature and other materials, in recent years, with the development of new agriculture, intelligent cultivation technology has been widely studied. It mainly includes soilless cultivation technology, plant block seedling cultivation technology, water solution monitoring technology, red and blue light regulation plant growth technology, etc. Potted plants can grow healthily with these techniques when left unattended. Therefore, the comprehensive application of these technologies in the scheme design will be helpful to the realization of related functions and design.

4.3 Scheme Design and User Evaluation Centered Scheme Selection

The design of the scheme and the selection of the scheme are the third and fourth stages in the time dimension. These two stages are almost equivalent in terms of time and logic dimensions; In logic dimension, they are regarded as two stages: design proposal and design evaluation. In these two stages, the design of specific product shape and function is carried out at first, and then the best scheme is selected by the evaluation method centered on user evaluation. In the process of design and evaluation, all kinds of knowledge in the knowledge dimension will be fully invoked. For example, in the specific appearance design, the knowledge of design psychology and modeling will be used to meet the aesthetic requirements of users, and the means of hand-sketching and computer modeling will be used to display the design scheme; The function of the product needs to be determined by referring to the botanical knowledge acquired in the previous step.

On the basis of the obtained design scheme, the final design scheme is screened and determined, and the scheme is evaluated before refinement to verify its desirability. analytic hierarchy process (AHP) is used to evaluate the scheme. AHP is a decision-making method for quantitative analysis of qualitative indicators. By introducing quantitative evaluation criteria into qualitative indicators, it can effectively improve the accuracy and scientificity of decision making [7]. The detailed analysis process is as follows.

First, the factors considered in the design process are divided into four aspects according to the difference in nature: functionality, technical feasibility, integrity and aesthetics, as shown in Table 3.

In addition, 10 horticultural industry workers and 10 designers were invited to compare, discuss and score the above four factors according to the requirements of Table 3, and then the obtained data were sorted out.

The numbers entered in the table are determined by the difference in importance of the two factors. When the importance of the column factor is the same as that of the row factor, fill in 1, and in the same way, the intensity of importance can be divided into five levels: equally important, slightly important, generally important, relatively important and very important. The corresponding Numbers are 1, 3, 5, 7 and 9 respectively. Fill in 2, 4, 6, 8 if there is a situation between the two levels. If the opposite happens, that is, when the row factor is more important than the column factor, fill in the reciprocal of the

Table 3. Design evaluation system property index

	Indicator	Particulars
Evaluation system	Functionality	Easy to operate
		Load the plant
		Provide illumination
		Provide water&fertilizer
		Monitor growth
		Provide water&fertilizer
		Record
		Cultivation of a variety of plants is allowed
	Technical feasibility	The material process conforms to the production standard
		The structure conforms to the existing production technology
		The technology is ready
	Aesthetics	Do not cover up the form of plants, easy to ornamental plants
		Blend in and decorate the home environment to a certain extent
	Integrity	Help with plant selection and purchase
		Covers the entire life cycle of the plant

corresponding figure, such as 1/3, 1/5, etc. Finally, according to the weight calculation formula, the general scoring situation of each table is obtained as shown in Table 4.

Table 4. Scoring result

Importance evaluation	Functionality	Technical feasibility	Aesthetics	Integrity
Functionality	1	4	5	3
Technical feasibility	0.25	1	2	0.25
Aesthetics	0.2	0.5	1	0.2
Integrity	0.33	4	5	1

This table is taken as a reference and calculated according to the weight calculation formula

$$W_i = \frac{1}{\mathrm{n}} \sum_{j=1}^{n} \frac{\mathrm{a}_{ij}}{\sum_{k=1}^{\mathrm{n}} \mathrm{a}_{kj}} \tag{1}$$

Then we can get the weight value of each index, as shown in Table 5.

Table 5. Weight of 4 indicators

Importance evaluation	Functionality W1	Technical feasibility W2	Aesthetics W3	Integrity W4
Weighted value	0.5101	0.1139	0.3043	0.0717

In order to verify the rationality of the weight table, consistency test is carried out.

First, the maximum eigenvalue of the matrix is calculated. According to the calculation formula of maximum eigenvalue

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{\sum_{j=1}^{n} a_{ij}\omega_j}{\omega_i} \tag{2}$$

The maximum eigenvalue of the matrix is obtained: $\lambda_{max} = 4.1930$.

Next, its consistency index is calculated

$$C.I. = \frac{\lambda_{max} - n}{n - 1} = 0.061 \tag{3}$$

The reference table shows that the average random consistency index $R.I. = 0.90$.

Therefore, the test coefficient can be calculated

$$C.R. = \frac{C.I.}{R.I.} \approx 0.068 < 0.1 \tag{4}$$

After calculation, it can be concluded that the test coefficient of this table is about 0.068, which passes the consistency test.

Next, the participants were asked to rate each indicator again. Five evaluation indicators were established, which were very good, good, general, poor and very poor, respectively, represented by 2, 1, 0, −1 and −2. The obtained data are normalized to obtain the fuzzy evaluation matrix of the design:

$$R = \begin{Bmatrix} 0.50\ 0.30\ 0.00\ 0.10\ 0.00 \\ 0.10\ 0.40\ 0.10\ 0.20\ 0.10 \\ 0.20\ 0.40\ 0.20\ 0.20\ 0.00 \\ 0.30\ 0.30\ 0.10\ 0.20\ 0.10 \end{Bmatrix} \tag{5}$$

The matrix is calculated using the weighted average type of fuzzy operator, the final draw five evaluation set weights are: 0.378, 0.364, 0.081, 0.157, 0.020. It can be seen from the above table that the best weight value in the five comments is the highest (0.378), followed by the best weight value (0.363). Combined with the maximum membership rule, it can be known that the final comprehensive evaluation result is "very good" and the overall scheme is highly satisfactory. Therefore, this design will be regarded as the final design for further improvement. In addition, it can be seen that the evaluation degree of completeness in the scheme is relatively general, because the design of the supporting APP has not been completed yet, and the design of this part will be strengthened in the next step.

4.4 Design of Supporting APP

As the fifth stage of the time dimension, the design of supporting APP can complete the design scheme, which is complementary to the design of the physical product obtained in the fourth stage, and can also prepare for the next stage. In the logical dimension, this stage is completed by repeating the design proposal and design evaluation. The design knowledge of interaction design and interface design in the knowledge dimension is invoked, and the page prototype is made based on the function classification and ordering obtained in the early stage, so as to ensure that the supporting APP can provide users with planting functions in all aspects in combination with the physical design. Some of the resulting high-fidelity prototypes are shown in Fig. 2.

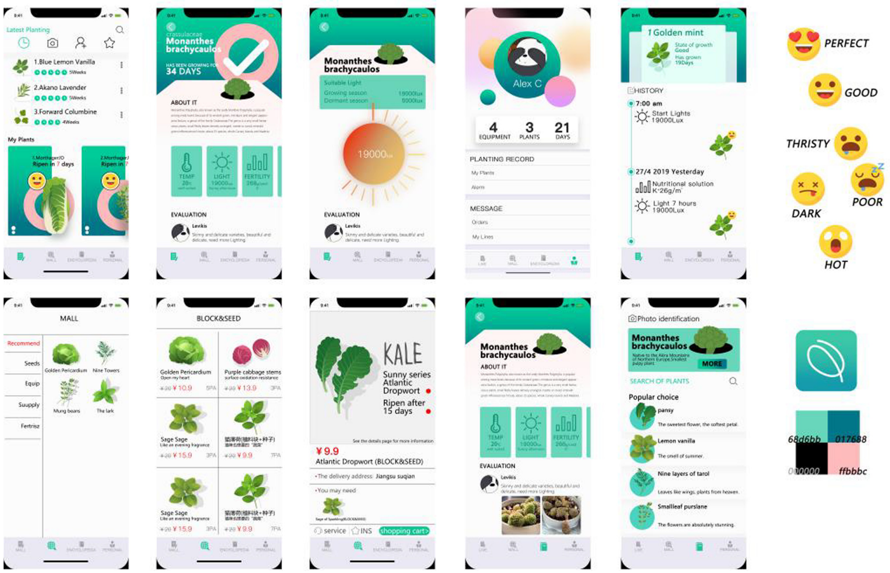

Fig. 2. APP design

4.5 Final Design Project Introduction

To sum up, the final overall design scheme is shown in Fig. 3.

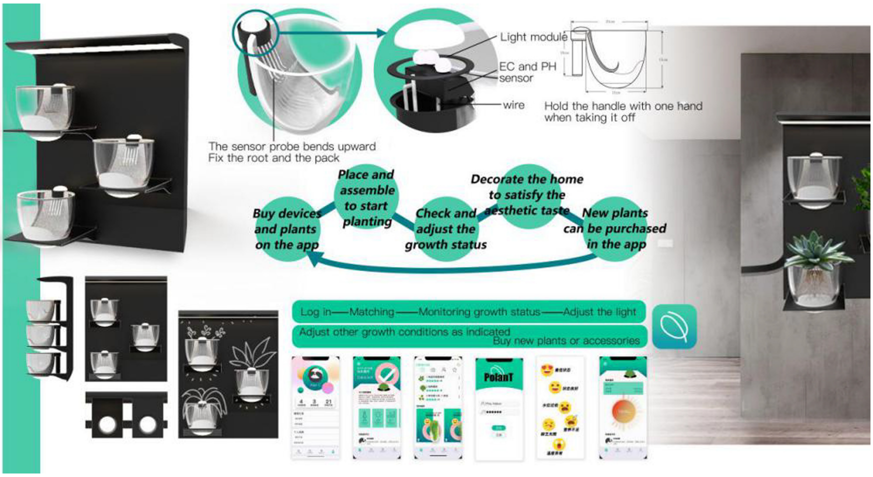

Fig. 3. Final design

The final design project is composed of hardware and APP. The hardware part is mainly composed of vertical bracket and modular planting cup. The whole bracket is connected to the power supply, and the implant cup can be connected to the power supply for operation. A single implant cup is composed of light module, EC (aqueous solution electrical conduction) sensor and pH sensor, etc. Such combination simulates light and can monitor all indexes of aqueous solution. After transplanting, the plant can be fixed in the planting cup and cultivated soilless with nutrient solution. Users can easily take the planting cup for observation or other operations such as adding water, changing water, etc. The software is operated mainly through the mobile APP. Users can check the water, nutrition and light of plants at any time.

The main difference between this design and existing products lies in the vertical design of the scheme and the design of the planting cup module. The vertical design can not only cover the form of the plant itself, but also save interior space; Combined with the planting cup module, the user's operating costs can also be reduced. Convenience and freedom of operation are provided by the planting cup. Multiple planting cups can be randomly matched and combined to create personalized planting combinations, and the fun of using the product will be enhanced.

The overall scheme is easy to operate, and the overall shape is mainly made of matte plastic and translucent acrylic materials, with black, white and gray tones to create a refined visual sense, which can be well integrated into the daily home environment.

4.6 Product Production and Update

As the final stages, the production and update of the product are basically consistent in terms of logical dimension and time dimension. In the production process of products, technology, cost, time and other factors need to be considered comprehensively; the support APP also needs to be developed synchronously. After the product launches, user feedback will be collected for subsequent optimization and improvement.

5 Conclusion

In order to improve the use experience of household intelligent planting products, Hall three-dimensional structure theory is used in the planning and design process, and a series of user evaluation methods including Kano model and AHP are used in the analysis of the design process. The final design results show that Hall three-dimensional structure theory can guide the design process well, and the design based on user evaluation can also improve the use experience of the product.

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