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APPLIED RESEARCH

Optimization Strategies for the Modular Resource Construction of Art Gallery's Exhibition Halls Based on Kansei Engineering

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This work involved human subjects or animals in its research. The authors confirm that all human/animal subject research procedures and protocols are exempt from review board approval.

ABSTRACT With the popularization of community's micro-renewal and sustainability concept, the improvement of residents' satisfaction and the reasonable allocation of resources have become the core elements in the effectiveness evaluation of community renewal. On the basis of fully satisfying the needs of users, building spatial forms through the emotional needs of users can effectively solve the problem of rational allocation of resources in community regeneration, so as to avoid the cost consumption of design trial and error. This paper explores the mapping relationships between residents' emotional images and the spatial form of mobile exhibition halls in community's art gallery under Kansei Engineering (KE). The aim is to validate the possibility of the above objectives in addressing the sustainability renewal of a community.First of all, relevant samples are collected and Web crawler technology is used to retrieve relevant Kansei words, and the most representative Kansei words relative to the samples in the exhibition hall are collected. Secondly, the data values corresponding to Kansei words are obtained by using Likert scale, and the Exploratory factor analysis (EFA) is used to cluster Kansei words to obtain seven most representative emotional semantic words, namely, natural, bright, diverse, simple, fun and sustainable. Moreover, in combination with principal component analysis (PCA), three factors structures are obtained, namely the sense of clearness, sense of lucidity and sense of symbiosis. Analytical Hierarchy Process (AHP) is used to get the index weight ranking of each factor structure. The weights, in descending order, are as follows: symbiosis at 0.59, lucidity at 0.33, and clearness at 0.09.Finally, the Quality Function Deployment (QFD) tool is used to map the emotional image of the user and the form of the exhibition hall's components. This process culminates in the formulation of a comprehensive design solutions conprised of six components: background wall of no.3, vehicle placement of no.3, ceiling shape of no.4, lighting of no.4, corridor shape of no.1, front desk shape of no.2. Based on KE, assemblability and recyclable waste wood can, to a certain extent, the exhibition hall design model meets the emotional needs of residents in different communities through diversified exhibition hall assembly design. In addition, the material and assembly mode are also responsive to global sustainable development.

INDEX TERMS Kansei engineering, mobile exhibition halls, exploratory factor analysis, analytical hierarchy process, quality function deployment.

I. INTRODUCTION

In recent years, in the exploration of community regeneration models, there has been an increasing focus on issues such as the needs and co-construction of community users and the allocation of community ecological resources. However, most community regeneration tends to rely on a static community structure detection method based on population mobility [1], [2], [3] to address issues the diversifying and changing needs of users, which leads to the fact that

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structural adjustments in community development are usually difficult to meet the immediate needs of the public in the community [4].Moreover, in the process of sustainable community renewal with the help of highly sophisticated technologies such as augmented reality (AR), although there is a certain improvemnet in spatial convenience and a response to the public's physical and psychological needs [5], [6], it lacks the consideration of objective factors such as the public's emotional perception and the ability to adapt to advanced technologies. Therefore, while technology addresses the needs of the life,it also gives rise to issues of demand deviation, such as the problem of the elderly's heterogeneity in the process of the adaptation of the digital media [7], [8]. However, among the various key requirements for promoting sustainable development, aside from addressing issues related to ecological service systems and sustainable supply management, it's even more crucial to create a comfortable and convenient community environments. Therefore, the study chose to collect the emotional perceived needs of the permanent residents of the community and comparatively analyse their relative importance in a comparative manner, which is important for clarifying whether and how community user needs contribute to the creation of a sustainable community spatial form.

Under the premise that the basic functional needs of users have been effectively improved, the psychological and perceptual needs can significantly enhance overall satisfaction with the space. The external form of space often contains a unified and typical emotional demand. Based on the above development trend, in recent years within the field of art museum research, planners of space have increasingly aimed to improve the physiological and psychological health needs in daily life space, and gradually expand the art gallery exhibition hall's spaces into a multifunctional complex covering education, commerce, medical care, leisure and entertainment [9], [10]. Futhermore, there has been a gradual development trend of expanding from urban centres to community spaces and even into digital spaces [11], [12].On the other hand, efforts are focused on enhancing users' perceived needs, bridging design deviations and spatial conflicts. For instance, concepts such as Inclusive Design [13] and Co-designing [14] are gradually incorporated into the design of community's art gallery soace, targeting public's needs and even the marginalised groups'needs. By exploring the public's emotional needs of the public to translate spatial characteristics, these approaches aim to increase public engagement with the space and enhance the sense of well-being in daily life [15], [16], [17].

However, traditional community regeneration models and spatial form design rely heavily on the work experience and subjective judgement of planners, designers and others. The degree of user participation in the design process is limited, and even if the factors affecting users' intention to participate in the space can be deduced through semi-structured interviews [18], it is difficult to completely exclude the involvement of experts' subjective opinions in the process of analysing and refining the information. In addition, the lack of an efficient and objective way of analysing information to draw relatively objective conclusions about users' needs has led to an increase in the duration of the design, and the corresponding costs in terms of labour and time.Participation in the space is often a measure of user satisfaction, and if the subsequent evaluation of the space continues to decrease, the consequent loss of local resources can lead to a significant increase in the cost of trial and error, which is contrary to the needs of sustainable development. Therefore, determining how to distil accurate user perceptions through parametric processing, and how to map user emotions to spatial features, is undoubtedly the key to realising sustainable community regeneration on the basis of meeting the actual emotional needs of users.

A. KANSEI ENGINEERING

Kansei Engineering (KE), also known as ''sense engineering'', ''affective availability''was proposed by Mitsuo Nagamachi in 1970. It is a translation technique that converts qualified emotional perception into the morphological characteristics of product components [19]. KE aims to capture the internal emotional variables of users through mathematical scales [20], thus analyzing the correlation of variables through statistical calculations and forming a complete set of design specifications [21], [22]. KE can be used to analyze and refine the design features that satisfy the user's perceived needs, thereby achieving objectives such as enhancing product sales. Consequently, KE has been widely applied in interdisciplinary research across numerous fields, including product design [23], [24], vehicular interaction [25], and living spaces [26].

In the study of Caratelli and Misiri, they adopted the semantic difference method (SD) to map user perception and semantically related descriptions, and combined with the KE research framework, thus building a public space shared by heterogeneous users that effectively improves the well-being of community space [27]. KE combined with the mobility theory, to establish a correlation between users' perceptions and the formal elements of the public space, which resulted in an effective and accurate spatial appearance. This leads to effective and accurate spatial appearance design strategies [28]. Papantonopoulos et al., showed that by using KE to assess the correlation attributes between lighting variables and users' affective imagery, and using this to guide the lighting design of indoor spaces, spatial lighting design goals such as optimising spatial effectiveness can ultimately be achieved [29].

While KE has been widely used in product design, automotive design and other fields, its integration with spatial and environmental design remains significantly underdeveloped. Additionally, under the traditional KE research framework, data analysis methodologies like SD, SEM, Kano usually need to be based on a large amount of user demand information research, which incurs high experimental costs in both

data collection and data summarization. Various interview experiments not only incurs high experimental costs in data collection and summarization but also faces geographical limitations in information collection and subjectivity in participant selection or data filtering, which ultimately leads to considerable deviations in experimental outcomes. Methods such as TRIZ theory often focus on analyzing key features in specific form design processes with reference to an ideal path.This approach lacks a multi-dimensional evaluation of various characteristics, thereby tending to skew experimental results towards an idealized state and away from practical realities.

Open online platforms often contain vast amounts of user comments, which are mostly composed of various nouns and adjectives containing emotional tendencies (e.g., interesting, bright), etc. The user feedback system can provide an efficient way to collect information for design planners to optimise the experience of using products and spatial environments. The in-depth mining of user feedback on product use and spatial environment experience (e.g. the evaluation system of the booking interface of accommodations and hotel rooms) can provide design planners with an efficient way to collect information, and build a more accurate and objective data base for optimising design strategies and reducing design analysis costs.

In order to be able to achieve the above related goals and to efficiently apply the analysis data to the study of spatial form design of mobile exhibition halls in community art gallery exhibition hall under the KE framework, we designed a technical framework for efficiently collecting and analysing information about users' affective needs, and for distinguishing the mapping relationship between the affective needs and the form design features. This paper proposes an analysis system tailored to the spatial form design of mobile exhibition halls in community art gallery, namely, a perceptual engineering system that integrates EFA/AHP/QFD.

Firstly, this study utilized Python and the Scrapy web crawling framework to conduct web scraping searches on user reviews related to community's art gallery exhibition hall across multiple design websites, performing preliminary filtering of user comments based on the occurrence of word frequency and other elements. To extract key emotion words from the huge amount of user comment information, a relevant expert group was invited to conduct vocabulary screening, and vocabulary assessment from multiple perspectives was used to improve the accuracy in the screening of emotion word information. The results show that this phase of the study greatly reduces the cost of data collection (time cost, labour cost, etc.).At the same time, the emotional vocabulary selected through dual filtering by users and experts could, to a certain extent, ensure the accuracy of the emotional vocabulary.

Secondly, in order to discriminate the relative importance as well as the correlation among emotion words, this paper proposes a quantitative analysis model of EFA/AHP. With the help of EFA, the correlation between various emotion words is mined, while PCA is combined to generate the factor structure between emotion words in this study, and after that, AHP is used to further analyse the weight ordering of emotional words. The results indicate that this analytical process aids designers in better discerning the primary and secondary relationships among various emotional words during the later stages of the design process, and achieves a more accurate in the inter-mapping of emotional vocabularies and design features.

Thirdly, based on the design principles for art gallery exhibition halls and integrated ecological concepts proposed in current related theories, this paper adopts the Delphi method for expert consultation during the selection process of the design features to ensure that these features are well-suited to contemporary community environments. Furthermore, the mapping relationship between the emotional vocabulary and the design components is calculated through QFD analysis, combining the relevant conclusions of the weighting analysis in the above study. The results show that the method can well correspond key emotional vocabulary and design features to each other, which also helps designers to quickly identify the key design features to be retained in the final solution generation process.

Lastly, the arrangement of the remaining sections of this paper is as follows: Section II analyses and summarizes the relevant research methods and points out the strengths and weaknesses of each type of method; Section III introduces the technical framework for the study of the spatial form of the mobile exhibition hall of the community art gallery, and the detailed process of the study of the application of the various technologies; Section IV gives the relevant design solutions generated based on the data analyzed in the study and evaluates the design practice; Section V summarizes the research methodology, and discusses the differences between the similar methods, etc.; and Section VI sums up the main contributions of the study, as well as its limitations at the present time.

II. RELEVANT METHODS

A. EXPLORATORY FACTOR ANALYSIS

Exploratory factor Analysis (EFA) was proposed by Spearman in the early 20th century (1904) and has been widely used in many fields such as psychometrics [30], Building Information Modeling (BIM) [31], sustainable building projects [32]. It is a statistical technique used to improve factor correlation analysis [33], [34]. Its principle is mainly to analyze the factor correlation commonality(factor load) and dimension reduction of multiple observed variables through dimensionality reduction, and answer the possibility correlation questions among variables, thus obtaining the underlying factor structure among variables [35], [36].

Ayalew et al., used Spss to conduct EFA analysis of indicators in their studies, which would achieve effective dimensionality reduction of data set size and and analyze

TABLE 1. KMO measurement standard.

KMO	Applicability of Factor Analysis
0.9 or more	Perfect fit
0.8-0.9	Fit
0.7-0.8	Fair
0.6-0.7	Grudging
0.5-0.6	Unsuitable
0.5 or less	Very unsuitable

factor structure among variables from the target layer's observed variables [37]. KMO measure (Table 1) and Bartlett sphericity test is used to determine the initial correlation of factors; the calculation results obtained from equation (1) and equation (2) are used to evaluate whether the structural reliability in the study meet the research criteria [38]. In the formula, r_{ij} is the correlation coefficient of variables x_i and x_j; p_{ij} is the corresponding partial correlation coefficient of variables x_i and x_j. S is the total variance of the same type of problem; S_i is the variance of the score obtained by the variable i.

$$KMO = \frac{\sum\sum_{i\neq j} r_{ij}^2}{\sum\sum_{i\neq j} r_{ij}^2 + \sum\sum_{i\neq j} p_{ij}^2} \tag{1}$$

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k} S_i^2}{S^2}\right) \tag{2}$$

Effective common factors analysis are screened based on the criterion that Kaiser's eigenvalue is greater than 1, and the maximum variance factor rotation method (orthogonal rotation method or oblique rotation method) is calculated in combination with equation (3) and the relevant factor load rotation matrix is obtained according to equation (4); The attribution relationship in the factor structure is further determined by evaluating the factor load coefficient in the matrix (the load size of variables on each common factor) [39], [40], [41].

$$A_2 = A_1 T \tag{3}$$

$$F_m = a_{m0} + a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n \tag{4}$$

In the formula: A_1 is the matrix before rotation; A_2 is the matrix after rotation; T is an orthogonal matrix; k is the number of factors; n is the number of original factors; F_k is the factor of No. k. a_{k0} is the constant term relative to the factor of No. k. a_{kn} is the load coefficient of No. n relative to the original factor of No. n. x_n is the original factor of No. n.

In recent years' research on EFA of design field, Jiang et al., (2023) adopted EFA, CFA and other methods to analyze the structure of the three factors: fantasy, emotion and fun in the ultra-ecological experience of luxury brands. At the same time, the research results show that the design model derived from this methodology can effectively improve the happiness of users in the consumption experience [42]. Murtagh and Frost explored the intrinsic motivation of private garden construction, analyzed various types of motivation through EFA and summarized three potential factor structures, showing that correct intervention of motivation can effectively stimulate the construction of private garden and even maintenance intention of environmental governance [43].

The relevant application research of EFA can generally clarify the correlation attributes among various factors through dimensionality reduction, thus guiding design and improving products' economic benefits and spatial satisfaction. Therefore, the computational analysis of EFA is also helpful to analyze the correlation structure of emotional vocabularies in the researches on mobile exhibition halls of community art galleries. The factor structure of the Kansei words corresponding to the space is obtained through the calculation and analysis of EFA dimensionality reduction so as to ensure that during the transformation process of public spaces such as community art galleries, relatively important spatial emotion elements are reasonably selected for designers and classified into types, thus correcting the factor type deviation in the emotional needs of users generated under the subjective guidance of designers. However, the analysis results of EFA do not involve the relative importance ranking of Kansei words. Therefore, how to construct the primary and secondary correlation of emotion factors during the generation of specific design schemes? How is it reflected in the space? How should various emotional factors be arranged in the space to stimulate the maximum perception effectiveness? How to construct the mapping relationship between affective factors and spatial components? Such related problems are still difficult to be effectively solved in the research process of EFA. In order to further improve the design strategy based on EFA, EFA should be appropriately considered to combine with other technologies.

B. ANALYTICAL HIERARCHY PROCESS

In the 1970s, Saaty, a scholar from University of Pittsburgh, proposed the Analytic Hierarchy Process (AHP) [44]. This method is used as a multi-criteria decision analysis (MCDM) technique [45], [46], [47] in urban road evaluation system [48], sustainable composite materials [49], refugee shelters [50] and many other fields are widely used. AHP hierarchy analysis aims to combine qualitative and quantitative research, and obtain consistency analysis, weighting coefficient distribution and other relevant values through systematic analysis of comparison matrix, thus judging the relative order of advantages and disadvantages among variables. Finally, reasonable allocation of resources can be realized [51], [52], [53].

In the process of AHP analysis, Saaty1-9 scale system (Table 2) is adopted to obtain the score values of each index (5) and (6),and it is combined with the paired comparison matrix (7) to realize the relative importance judgment of each two indicators [54].

$$a_i, a_j \ (i, j = 1, 2, \cdots, n) \tag{5}$$

$$a_{ij} = \text{The importance of } i\text{relative to } j \tag{6}$$

TABLE 2. Saaty's AHP scale.

Number	Linguistic Scale
1	Equal importance (HU)
3	Moderate importance (U)
5	Strong importance (N)
7	Very strong importance (F)
9	Extreme importance (HF)
2, 4, 6, 8	Intermediate values between adjacent scale values

$$A = \begin{pmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{pmatrix} \tag{7}$$

The geometric average method is used to calculate the weights of indicators in the matrix [55]. The eigenvector V_i is determined by the objective function (8). In the process of data normalization, the value of V_i is substituted into the objective function (9) to obtain the weighting coefficient w_i of each index. Finally, the eigenvector (weight vector) W is obtained by the objective function (10).

$$V_i = \left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}} \tag{8}$$

$$w_i = \frac{V_i}{\sum_{m=1}^{n}\left(\prod_{j=1}^{n} a_{mj}\right)^{\frac{1}{n}}} \tag{9}$$

$$W = (w_1, w_2, \cdots, w_n)^T \tag{10}$$

In the formula, V_i is the average value; w_i is the average value of each weight; W is the weight vector.

In the process of calculating the weight values of the matrix, the consistency test of the matrix should be carried out to ensure the validity of the matrix results. The value of consistency ratio, as an important reference to measure the validity of the matrix, can be obtained by a series of calculations in formulas (11), (12) and (13). The maximum eigenvalue λ_{max} is obtained by formula (11); the consistency index CI is calculated in formula (12). The random consistency index RI is further obtained by formula (13); finally, the value is substituted into the formula (14) to obtain the consistency ratio CR [56], [57].

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(AW)_i}{nw_i} \tag{11}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{12}$$

$$RI = \frac{CI_1 + CI_2 + \cdots + CI_n}{n} \tag{13}$$

$$CR = \frac{CI}{RI} \tag{14}$$

In the formula, λ_{max} is the largest eigenvalue; CI is the consistency index; RI is the random consistency index; CR is the random consistency ratio.

The numerical standard of consistency ratio CR and the random consistency index value are adopted to support the validity of the value generated by the matrix. When CR is less than 0.1, it is determined that the degree of inconsistency of the matrix is within the controllable range, and the rationality of the data is tested.

In the evaluation research of indoor building environment conditions, AHP analysis method is used to calculate the relative weight of spatial impact factors, and multi-attribute utility theory (MAUT) is combined to evaluate the impact factors in the spatial environment. Thus, an evaluation model of indoor building environmental state is proposed to support the objective evaluation of architectural space [58]. In the construction of residential performance evaluation system, AHP can effectively analyze the relative importance of items or factors, and find that the formed livability evaluation model based on AHP weight analysis can improve users' satisfaction in terms of spatial performance and spatial intrinsic value [59].

Scientific and reasonable calculation of AHP in previous studies can generate the weight value of factors to clarify the priority ranking among factors, so AHP is widely used in the establishment of evaluation system such as education, marketing and product design. Similarly, AHP is also applicable to the hierarchical analysis of emotional vocabulary in the mobile exhibition hall of community's art gallery. By taking advantage of AHP 's hierarchical analysis, the author tries to solve problems such as the importance ranking of factors that are difficult to calculate in EFA analysis through the analysis model of EFA/AHP in this paper, thus ensuring the rationality and objectivity of emotional image mapping and spatial focus arrangement in the specific design process. Although AHP can further clarify the relative importance of factors at all levels under the factor structure, it is still difficult to effectively solve the problems of mutual mapping between emotional factors and spatial modeling components, and the objectivity of design results lacks effective guarantee.

C. QUALITY FUNCTION DEPLOYMENT

QFD is a quality planning tool to bridge the deviation between users' expectation and design [60]. It was proposed by Akao in 1996 and has bee applied to various research fields such as sustainable furniture design [61], aging-friendly home space design [62] and commercial space design [63] during the decades of development. The application of QFD is mainly based on the HoQ quality model (Figure. 1), aiming at building a relationship matrix including six important levels such users' needs and technical needs. It translates users' requirements into quality characteristics of design or service [64], [65].

QFD analysis maps specific design performance and provides stability assessment by identifying users' needs and prioritizing requirements. On the basis of obtaining the weighted coefficient of variables, the HoQ quality model and formula (15) and (16) are used to calculated the matrix relationship of HoQ; the key features of the design corresponding to the key requirements of users are

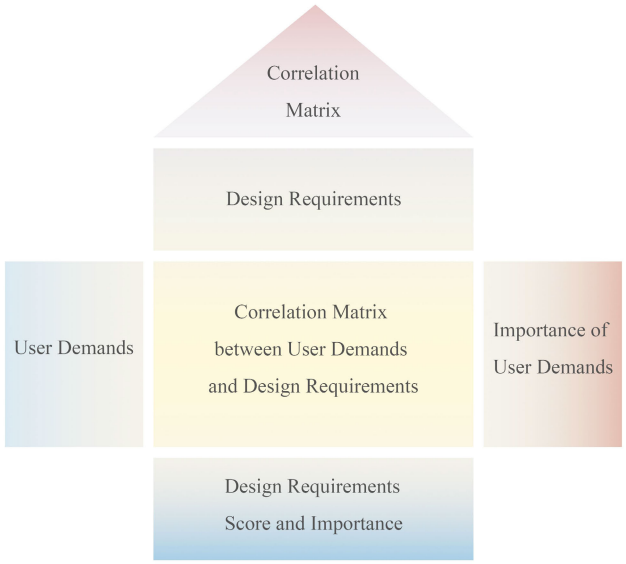

FIGURE 1. House of quality diagram.

quickly identified through the comparative analysis of data. Moreover, by prioritizing, the resources are made appropriate allocation [66], [67].

$$H_j = \sum_{i=1}^{q} W_i P_{ij} \ (j = 0, 1, 2, \cdots, n) \tag{15}$$

$$H_k = \frac{H_j}{\sum_{i=1}^{q} W_i H_j} \ (i = 0, 1, 2, \cdots, n) \tag{16}$$

In the formula, H_j is the absolute weight value of the house of quality; H_k is the perceptual semantic weight value calculated by AHP; P_{ij} is the associated value; W_i is the relative weight value of the house of quality.

Researches on the transformation of traditional architecture into commercial architecture show that QFD can effectively realize the commercial translation of traditional features of architecture in place, and at the same time it is verified to effectively retain cultural relics in terms of architectural shape, size and manual skills, and also stimulated the commercial attraction of architecture [68]; Researches on the update and development of intelligent building technology show that QFD quality function deployment according to the priority ranking of technical needs can effectively improve the efficiency of resource allocation the the possibility of communication and cooperation among various stakeholders [69].

Based on the analysis mentioned above, although QFD is suitable for determining the technical features and the weigh of the features required to meet the needs of users, it still faces problems such as collecting Customer Requirements (CRs) and calculating the relative importance ranking of analysis information [70]. Therefore, in the process of building the mapping model of emotional vocabulary and design components, EFA factor dimension reduction analysis and AHP hierarchy analysis are made full use to solve the weight ranking problems of users' emotional needs, bridge the drawbacks of QFD quality function deployment, and form a set of sound and reasonable research and analysis process to obtain the final optimal design strategy.

III. RESEARCH PROCESS AND RESULTS

A. RESEARCH FRAMEWORK

Under the research framework of KE, a mobile exhibition hall design strategy of community's art gallery art that meets the emotional needs of community users an enhances community's attraction through EFA/HAP/QFD is developed in the paper. The research framework proposed in this paper is shown in Figure 2, which is mainly divided into several levels: First of all, the modeling samples of the exhibition hall space of the community's art gallery are retrieved through the website, and the sample set is obtained through screening. At the same time, the relevant websites of the design samples are retrieved and then the emotional vocabulary corresponding to the samples is collected by Web Crawler, thus the emotional vocabulary scale is obtained through experts' evaluation. Through the users' questionnaire survey related to KE and the expert group's re-check and evaluation to the Kansei words, the most representative indicators of Kansei words in the exhibition hall are screened out. Then EFA is used to reduce the dimensionality of related indicators, and the common factor structure of Kansei words is established. AHP is used to identify and analyze the importance of all kinds of Kansei words, and the weight ranking relationship of corresponding Kansei words is established according to the relative importance value of words. Based on the theory of new art gallery, the author uses Delphi method to split and screen the spatial components of the mobile exhibition hall of community's art gallery, thus obtaining the basic demand components of space structure. Finally, QFD is used to establish a mapping model between users' emotion and the mobile exhibition space's various components of the community art gallery. On this basis, the design scheme of the mobile exhibition space of the community's art gallery that best meets the community's public emotion is obtained.

B. COLLECTIONS OF SPACE MODELING SAMPLES OF EXHIBITION HALL IN THE COMMUNITY'S ART GALLERY

Under the goal of collecting design samples that meet the emotional needs of users, the author firstly takes ''art gallery'', ''exhibition hall of community's art gallery'' and other related terms as sample retrieval conditions, thus obtaining a preliminary sample set consisting of 100 art gallery exhibition hall's design images through various retrieval channels such as the Internet and magazines. Secondly, in order to solve the problems such as users' emotion deviation caused by low image quality in the process of investigation, 50 highly representative samples of art gallery exhibition are further screened out on the basis of original sample set. Finally, the expert group is invited to evaluate and screen the samples in terms of mobility and structural details. Based on the sample screening results mentioned

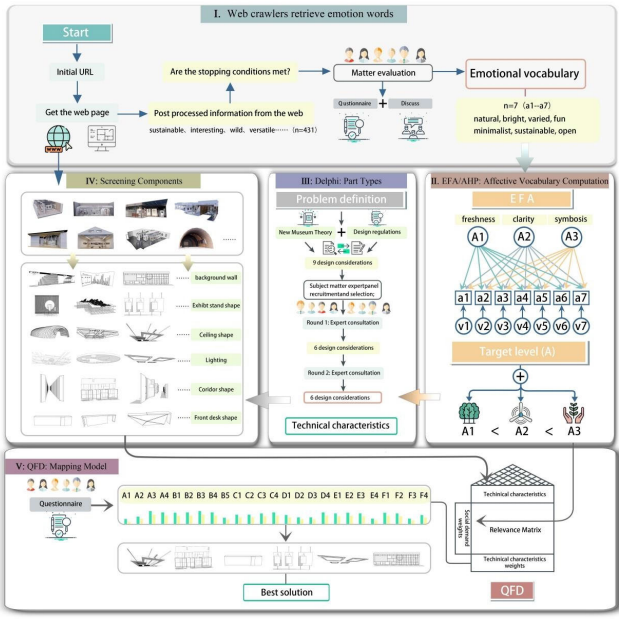

FIGURE 2. The proposed research framework.

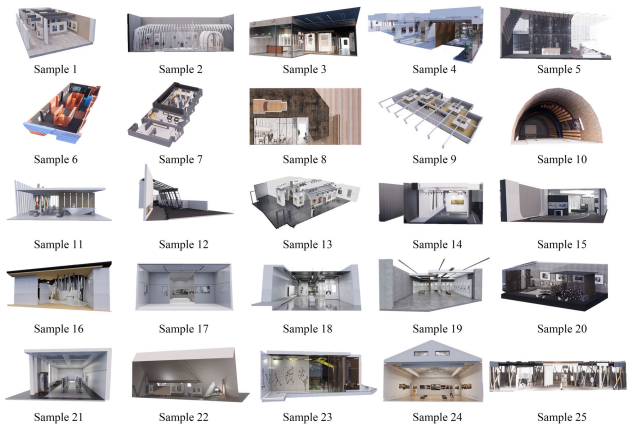

FIGURE 3. 25 Models of the art gallery design.

above, a modeling sample library of the community's art gallery exhibition hall containing 25 design samples is finally established, as shown in Figure 3.

C. COLLECTIONS OF KANSEI WORDS IN THE EXHIBITION SPACE OF COMMUNITY'S ART GALLERY

In the collection stage of Kansei words, first of all, the Web Crawler program is rewritten through Python to retrieve Kansei words from related websites. The specific retrieval pages can be seen in Figure 4. After searching the relevant information of Kansei words such as design description and use evaluation, 432 Kansei words are initially selected according to the frequency of words. Secondly, on the basis of removing words with low relevance and large semantic errors, 50 relevant design experts (with 25 women, 25 men, 25 designers who have been working for more than five years and 25 graduate and undergraduate students in the

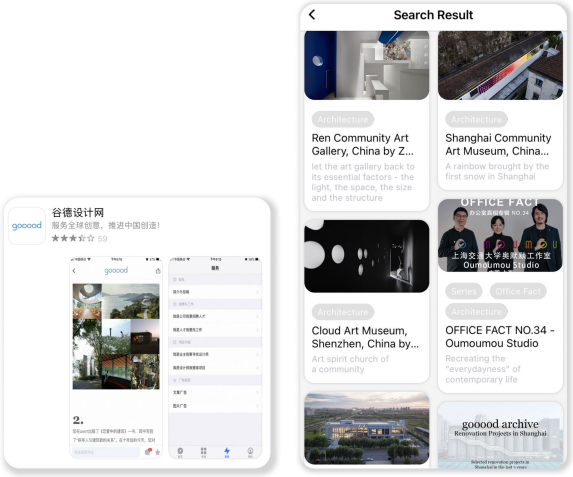

FIGURE 4. Websites of web crawler.

university)evaluate and screen the remaining 97 Kansei words, finally getting the 7 most representative Kansei words.

D. DIMENSION REDUCTION OF KANSEI WORDS IN EXPLORATORY FACTOR ANALYSIS

According to the summary mentioned above, the seven most representative Kansei words can be preliminarily summarized, which are natural, bright, diverse, simple, fun and sustainable. In order to fully understand the degree adaption between the various Kansei words corresponding to the exhibition hall's modeling of the community art gallery and the emotions of community users, a questionnaire survey is conducted on 101 community users by means of random sampling. The user group is mainly composed of retied employees and also includes some merchants and social people (the basic structure of the sample population includes 60 retired employees accounting for 59%, 30 merchants accounting for 30% and 11 members of the social persons accounting for 11%); A total of 101 questionnaires are issued in the survey, and 98 valid questionnaires are recovered, with an effective questionnaire rate of 97%. Five-point Likert scale is used to evaluate the survey (1=completely disagreed; 2=not quite disagreed; 3=difficult to judge; 4=relatively agreed; 5=quite agreed); 7 Kansei words are taken as the variables.Then make a score on the 25 modeling samples of exhibition hall space included in figure 3. In order to ensure the objectivity of the survey results, each sample's average score of Kansei words is obtained by statistical calculation. The average score results are shown in table 3.

After that, each sample's average score of Kansei words is imported into the IBM Spss27.0, and the dimensionality reduction classification of Kansei words is obtained through EFA analysis.The research of Arkadiusz et al.shows t7hat in the process of EFA analysis,KMO (Kaiser-Meyer-OLkin) and Bartlett sphericity tests must be carried out on scale data first. To verify whether the structural reliability and validity of the scale meet the basic research criteria for EFA analysis [71]. The experimental results show that the KMO

TABLE 3. Units for magnetic properties.

Sample Number	Natural	Bright	Diverse	Simple	Fun	Sustainable	Wide
1	3.96	3.79	4.19	4.23	3.63	3.89	4.27
2	3.86	3.81	3.93	4.29	3.71	3.74	3.79
3	3.70	3.73	3.81	3.81	3.79	3.99	3.68
4	3.97	3.84	3.95	3.90	3.81	3.79	3.62
5	3.70	3.59	3.90	3.79	3.64	3.93	3.96
6	3.89	3.79	4.04	3.96	3.89	3.85	3.64
7	3.73	3.79	3.93	3.99	3.81	3.58	3.79
8	3.95	3.93	3.77	4.30	3.79	3.90	3.64
9	3.81	3.88	3.93	4.12	3.88	3.88	3.70
10	3.95	3.77	4.03	4.16	3.97	4.00	3.92
11	3.75	3.68	3.67	3.95	3.86	3.89	3.93
12	3.95	3.95	3.93	3.90	3.78	3.97	3.92
13	3.96	3.84	3.99	4.03	3.64	3.78	3.85
14	3.63	3.95	3.81	3.68	3.97	3.96	3.85
15	3.74	3.73	3.88	3.62	4.15	3.93	3.97
16	3.84	3.89	3.92	3.93	3.82	4.11	3.97
17	3.70	3.82	3.67	3.75	3.86	3.88	3.79
18	3.81	4.08	4.00	4.10	3.99	3.92	3.73
19	3.74	3.75	3.79	3.93	4.03	3.82	3.84
20	3.77	3.68	3.86	3.60	3.84	3.89	3.75
21	3.70	3.60	3.85	3.81	3.73	4.04	3.95
22	4.01	3.73	3.93	3.85	3.68	3.68	4.12
23	3.81	3.92	3.79	3.88	3.93	3.68	3.88
24	3.70	3.93	4.04	3.78	3.97	4.12	3.85
25	3.79	3.81	3.78	3.85	3.81	3.97	3.68

value is 0.636; the approximate chi-square value is 33.192; the degree of freedom is 21, and P=0.044 (when the KMO value is greater than 0.5 and the Bartlett sphericity test value p is less than 0.05; the data is judged to be suitable for factor analysis). This data is statistically significant. Moreover, it is difficult to interpret the correlation matrix simply as the identity matrix [72]. In summary, the data can be carried out the factor analysis through EFA.

In the research stage of dimensionality reduction classification of Kansei words and construction of factor structure relationship of Kansei words, factor screening criteria proposed by Kaiser (feature root>1) and evaluation results of Cattel factor gravel map are mainly used as evaluation criteria for dividing factor structure [73]. In the experimental results, it can be clearly observed that after the third factor dimension, the feature roots of other residual factor indexes are all less than 1 and show an obvious downward trend. The specific results are shown in figure 5. At the same time, in the total variance interpretation of Kansei words obtained through the scale data analysis, the cumulative variance's contribution rate of the first three indicators is 72.451, which proves that three main factor dimension can be summarized on the basis of 7 Kansei words through dimensionality reduction analysis. The specific experimental results are shown in table 4.

In the common analysis, Caesar's normalized maximum variance method is used to carry out orthogonal rotation of emotion factors; the common factor variance grater than 0.3 and the factor load greater than 0.5 are taken as the criterion of component effectiveness and the display condition of component values respectively [74], [75]. Among them, the positive and negative corresponding to

TABLE 4. Total variance explained.

component	Initial eigenvalue			Extract the sum of squared loads			Rotating load sum of squares		
	Total	variance percentage %	cumulative percentage %	Total	variance percentage %	cumulative percentage %	Total	variance percentage %	cumulative percentage %
1	2.347	33.533	33.533	2.347	33.533	33.533	2.215	31.642	31.642
2	1.549	22.124	55.656	1.549	22.124	55.656	1.581	22.588	54.230
3	1.176	16.795	72.451	1.176	16.795	72.451	1.275	18.221	72.451
4	0.694	9.908	82.360						
5	0.473	6.759	89.118						
6	0.391	5.588	94.706						
7	.371	5.294	100.000						

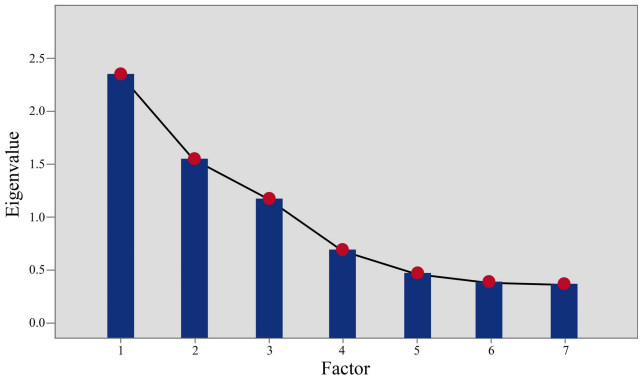

FIGURE 5. Scree plots.

TABLE 5. Component matrix after rotation.

Affective intention	Component		
	1	2	3
natural	0.812		
simple	0.772		
diverse	0.771		
wide		-0.756	
bright		0.752	
fun		0.605	
sustainable			0.829

TABLE 6. Component score coefficient matrix.

Affective intention	Component		
	1	2	3
natural	0.347	-0.018	-0.134
simple	0.258	0.489	0.177
diverse	0.388	-0.118	0.341
wide	0.335	0.139	-0.162
bright	-0.084	0.356	0.298
fun	0.040	-0.035	0.662
sustainable	0.106	-0.487	0.308

each component refer to the positive correlation and negative correlation among the indicators respectively. Therefore, the rotation component matrix of Kansei words based on users' emotion is constructed and the specific results are shown in Table 5. Principal component analysis [76] can be performed on seven sentimental factor indicators through CPA to obtain the sentimental lexical factor score coefficient and establish the component score coefficient matrix, as shown in table 6.

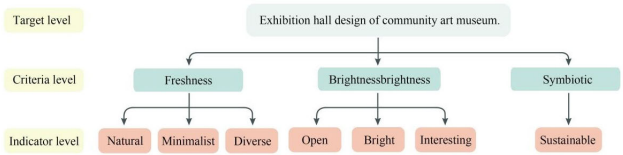

FIGURE 6. PCA analysis results based on EFA factor dimensionality reduction analysis.

TABLE 7. Expert 1.

A	A1	A2	A3	Eigenve-ctor	Weight Value
A1	1.000	0.333	0.200	0.345	0.11
A2	3.000	1.000	1.000	1.216	0.41
A3	5.000	1.000	1.000	1.439	0.48

In the analysis of users' Kansei words corresponding to the spatial modeling of the mobile hall of the community's art gallery, three main factor structures can be extracted based on the above experimental results.Factor structure 1 is named fresh factor, which contains three factor components, namely natural, simple and diverse. The factor structure 2 is named as bright factor, which contains 3 factors, namely, wide, bright and fun; The factor structure 3 is named as symbiotic factor, which contains 1 factor component, namely sustainable. The above three factor structures respectively correspond to the fresh sense, bright sense and symbiosis sense brought by the space modeling design of the community's art gallery, thus constructing the emotional structure of the space modeling design needs of the community's art gallery based on the sentimental needs of community users.

E. WEIGHT RANKING OF KANSEI WORDS IN HIERARCHICAL ANALYSIS

At this stage, based on the factor structure established by EFA analysis, the affective hierarchical structure model of the mobile exhibition space of the community's art gallery is obtained. The detains of the structure can be seen in figure 6. Secondly, in order to clarify the priority ranking relationship between the relative importance of Kansei words, six design experts in this field are invited to conduct relevant researches and evaluate the relative importance of various Kansei factors in the exhibition space by using the 1-9 scale method. The scoring rules of each expert are shown in table 7-12. In this stage of research, in order to reduce the complexity of Kansei factors' weight ranking, the criterion layer in the affective hierarchy model is mainly taken as the scoring target in the research process so as to establish the criterion layer judgment matrix of community users' sentimental needs.

CI=0.015RI=0.520CR=0.028<0.1
CI=0.000RI=0.520CR=0.000<0.1
CI=0.040RI=0.520CR=0.078<0.1
CI=0.015RI=0.520CR=0.028<0.1
CI=0.001RI=0.520CR=0.001<0.1
CI=0.005RI=0.520CR=0.009<0.1

After the weight value of each affective factor is obtained through AHP hierarchical analysis, it is calculated according to correlation matrix. In the weight ranking calculation of affective factor, the consistency of judgment matrix should be tested first, and the consistency test must comply with the consistency criterion proposed by Saaty. Only when the consistency ratio is less than 0.1, the data can be regarded to meet the consistency test; Based on the weight values of indicators scored by experts, the average weight values corresponding to each indicator are calculated to achieve the basic goal of improving the objectivity of data. Details of the final affective indicators' weight results are shown in table 13.

Based on the weight calculation results of the AHP mentioned above, the weight value of freshness is 0.09 in the structure of mainly three Kansei words, namely, freshness,

TABLE 8. Expert 2.

A	A1	A2	A3	Eigenve-ctor	Weight Value
A1	1.000	0.333	0.167	0.300	0.10
A2	3.000	1.000	0.500	0.900	0.30
A3	6.000	2.000	1.000	1.800	0.60

TABLE 9. Expert 3.

A	A1	A2	A3	Eigenve-ctor	Weight Value
A1	1.000	0.333	0.143	0.300	0.10
A2	3.000	1.000	1.000	1.168	0.39
A3	7.000	1.000	1.000	1.532	0.51

TABLE 10. Expert 4.

A	A1	A2	A3	Eigenve-ctor	Weight Value
A1	1.000	0.200	0.111	0.191	0.06
A2	5.000	1.000	0.333	0.802	0.27
A3	9.000	3.000	1.000	2.007	0.67

TABLE 11. Expert 5.

A	A1	A2	A3	Eigenve-ctor	Weight Value
A1	1.000	0.250	0.111	0.217	0.07
A2	4.000	1.000	0.500	0.904	0.30
A3	9.000	2.000	1.000	1.879	0.63

TABLE 12. Expert 6.

A	A1	A2	A3	Eigenve-ctor	Weight Value
A1	1.000	0.333	0.125	0.260	0.09
A2	3.000	1.000	0.500	0.858	0.29
A3	8.000	2.000	1.000	1.882	0.63

TABLE 13. Average value.

A	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Aver-age Weight
A1	0.11	0.10	0.10	0.06	0.07	0.09	0.09
A2	0.41	0.30	0.39	0.27	0.30	0.29	0.33
A3	0.48	0.60	0.51	0.67	0.63	0.63	0.59

brightness and symbiosis. The three subordinate Kansei words are natural, simple and diverse, indicating that the exhibition space of the community's art gallery should be able to bring people green, natural, concise and clever visual feelings in the shape. The symbiotic feeling structure with a weight of 0.59 contains the Kansei word: sustainable, indicating that the mobile exhibition space of the community's art gallery can create sustainable green visual feelings for the community users.

F. FORM ANALYSIS OF THE SPACE COMPONENTS IN THE EXHIBITION HALL OF THE COMMUNITY'S ART GALLERY

1) SELECTION OF INDICATORS AND SCREENING OF SUBJECTS

In the screening of exhibition hall's components of the gallery and on the basis of the core elements proposed in the theory of new museology [77] and the components required for exhibition halls proposed in the space-related planning of museums [78], nine important exhibition hall design components for art galleries are summarized: Exhibition equipment, auxiliary exhibition items, exhibition walls, lighting, ceiling, corridor (indoor/outdoor transition space), multi-purpose room, guide table and multimedia facilities. According to the above theory and practice, the early concept of the indicator scale is classified, and the initial indicator scale is established.

At this stage, the goal is to establish the composition standard of the spatial modeling parts of the mobile exhibition hall of the community's art gallery. Since the scope of the problem is closely related to the planning and research of the museum space design, ergonomics and many other fields, in this expert consultation,the expert group is mainly composed of relevant experts in this research field so as to conduct the investigation. In Delphi's relevant researches, more than 10 sample sizes can reasonably and effectively improve the accuracy of the survey results [79]. Based on the above requirements, the research consists of a heterogeneous group of 15 experts in related fields, including 5 graduate students in related majors, 5 undergraduate students in related majors and 5 professional designers (art gallery design, exhibition design, etc.) who have been working for more than 5 years.

2) INITIATIVE AND AUTHORITY OF THE EXPERTS

In this round of research, the motivation of experts in the survey is measured by their response to the questionnaire. The expert consultation survey is divided into two rounds of questionnaire responses; 15 questionnaires are issued in two rounds of expert consultation and a total of 15 questionnaires are received, with the questionnaire recovery rate and expert response rate reaching 100%. Formula (17) is used to calculate the authority coefficient (Cr) of the expert group, thus verifying the authority of the expert consultation results. Cs in the formula represents the expert's familiarity with the indicators; in the formula, Ca represents the basis of expert judgment basis. The value of Cs is calculated according to the assignment criteria of Cs and Ca, where 0.9=very familiar; 0.7=relatively familiar; 0.5=just so so; 0.3=less familiar; 0.1=very unfamiliar as a assignment criteria of Cs. The theoretical analysis (0.3= large; 0.2= medium; 0.1= small), practical experience (0.5= large; 0.4= medium; 0.3= small), references (0.1= large; 0.1= medium; 0.1= small) and intuitive feeling (0.1= large; 0.1= medium; 0.1= small) are taken as the evaluation reference standard for Ca. After calculation, the expert authority coefficient under each index dimension is finally obtained; the calculated result is Cs =0.727. Ca =0.953; Cr=0.840, where the value of Cr greater than or equal to 0.7 is used as the criterion to judge the validity of the result. Therefore, the above analysis shows that the data quality of this survey can be effectively guaranteed.

$$Cr = \frac{Ca + Cs}{2} \tag{17}$$

3) QUESTIONNAIRE SURVEY AND FORM ANALYSIS OF SPATIAL COMPONENTS

In the selection of the spatial modeling components of the community's art gallery, the experts make two rounds of questionnaire responses on the adaptive degree between the components and the space and its importance based on the 15 component samples initially obtained. Responses in both rounds are evaluated by using a 1-5 Likert scale scoring mechanism (1= completely unsuitable; 2= not quite suitable; 3= difficult to judge; 4= relatively suitable; 5= very suitable) and then appropriate modification suggestions are given; By calculating the variation coefficient (CV) corresponding to the indicator (taking CV<0.25 as the criterion) and Kendall coordination coefficient (W), the consistency of experts' opinions is objectively measured, so as to improve the reliability of indicator screening [80].

In the analysis of measuring the coordination degree of experts' opinions and determining the feasibility degree of research indicators, the numerical judgment criteria of Kendall coefficient (W) and feasibility coefficient (CV) must be satisfied respectively. Among them, the value range of Wis 0-1; if the value is larger, the coordination degree will be higher; The feasibility of the index is measured by the coefficient <0.25. After two rounds of expert consultation questionnaire responses, the coefficients of the two rounds are in the value range of 0-1, and the coefficient of Wis 0.866 in the second round, which is higher than the coefficient of Wthat is 0.666 in the first round. The experimental results show that the degree of experts opinion's coordination between the two round of expert consultation and Question&Answer has an obvious increasing trend; the analysis details are shown in table 14. The feasibility analysis results of the two rounds of indicators show that among the 9 indicators consulted by experts in the first round, the coefficients of 6 indicators are <0.25, and the coefficients of 3 indicators are <0.25. The coefficients of experts' consultation indexes in the second round are all <0.25. The results feasibility analysis in the first round are

TABLE 14. Two rounds of importance's comparative analysis.

item	first round importance	second round importance
W value	0.666	0.866
X2	79.870	64.967
P value	<0.001	<0.001

TABLE 15. Analysis results of the first round of experts' consultation.

item	x average value	standard deviation	CV coefficient of variation
exhibition equipment	4.40	0.828	0.19
auxiliary exhibition items	1.60	0.737	0.46
exhibition walls	3.40	0.828	0.24
lightening	3.13	0.743	0.24
corridor	3.33	0.724	0.22
multi-function rooms	1.87	0.743	0.40
guide table	2.53	0.516	0.20
multimedia facilities	1.40	0.507	0.36
ceiling	2.40	0.507	0.21

TABLE 16. Analysis results of experts' consultation in the second round.

item	x average value	standard deviation	CV coefficient of variation
exhibition equipment	4.60	0.507	0.11
exhibition equipment	2.87	0.352	0.12
lightening	3.33	0.488	0.15
corridor	2.93	0.458	0.16
guide table	1.80	0.414	0.23
ceiling	2.07	0.458	0.22

shown in table 15; the results of feasibility analysis in the second round are shown in table 16.

The calculation results in the two rounds of experts consultation show that in the results of first round's expert consultation, the feasibility of the three items including auxiliary exhibition item, multi-function room and multimedia facility are 0.46, 0.40, 0.36 respectively. The three indicators have been deleted after discussion by the expert group. According to the adjustment of the indicators made in the first round, the questionnaire survey of expert consultation is conducted in the second round mainly with six indicators. The results show that the feasibility of all the items in the second round is less than 0.25. After discussion, all the indicators in the second round of research are retained to from the component set of the mobile exhibition space in the community's art gallery.

Based on Delphi analysis, the modeling components of six exhibition spaces in the community's art gallery, including exhibition wall, exhibition equipment, ceiling, light, corridor and guide table are obtained. On this basis, combined with 25 exhibition space samples of the community's art galleries collected earlier, the components of them are disassembled

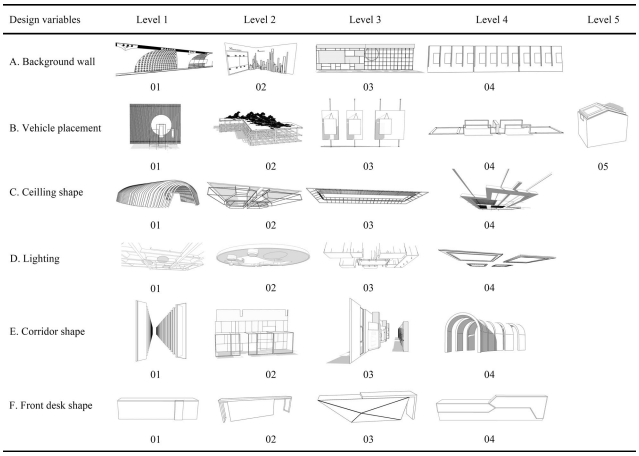

FIGURE 7. Morphological analysis of space components.

and analyzed. Finally four component forms of exhibition wall, ceiling, light, corridor and guide table are obtained respectively. Moreover the component forms of 5 exhibits are obtained as well. The detailed morphological analysis of each component is shown in figure 7.

G. QFD TO ESTABLISH THE MAPPING MODEL OF USER'S EMOTION

As QFD can effectively establish a mapping model between users' emotional images and design elements, it is used in this stage to build the connection between community users' emotional needs and the component forms of community's art gallery exhibition space. Based on the weight values of Kansei words calculated by AHP hierarchy analysis in the above research, the weight values of freshness, brightness and symbiosis are first introduced into the user demand side of QFD House of Quality, and the spatial form features of community art gallery exhibition hall obtained through sample form analysis are introduced into the design requirements of QFD House of Quality as key design features. Secondly, 10 experts in related fields, namely 5 graduate students in related majors and 5 museum exhibition hall's designers, are invited to evaluate the degree of conformity between the form of relevant spatial components in QFD and the emotional needs of users with reference to the proposed evaluation criteria of, and. Among them, corresponds to 3 points, indicating the weak correlation between the two indicators; Corresponds to 5 points, indicating the general correlation between the two indicators; Corresponding to 7 points, indicating the strong correlation between the two indicators, the correlation calculation value of the correlation matrix is obtained for the standard, and the corresponding morphological feature weight value of each level of indicators under each component type is calculated. The details of the calculation results are shown in Figure 8.

According to the analysis of the users' emotional mapping model of QFD House of Quality, the weight value of each spatial component form corresponding to the community's user emotion can be obtained, and the relatively most impor-

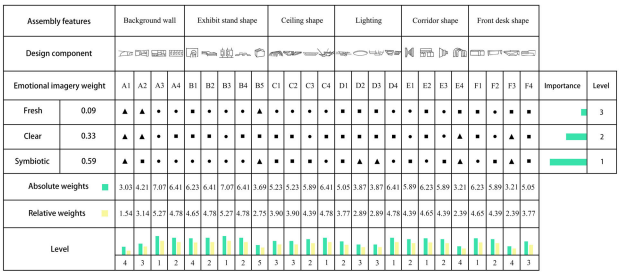

FIGURE 8. Emotional mapping model of QFD users.

tant single component form under each type of component form can be obtained through the ranking of the weight value. According to the analysis results in FIG. 8, it can be seen that the single component shape with the highest weight ratio under various component forms is as follows: Form 3 of the background wall modeling (the weight ratio is 5.27%; Form 3 of the exhibits modeling (weight ratio is 5.27%); Form 4 of ceiling modeling (4.78% weight); Form 4 of lighting modeling (weight ratio is 4.78%); Form 2 of corridor modeling (weight ratio is 4.65%); Form 1 of guide table modeling (weight ratio is 4.65%). Based on the above analysis, this analysis result can be used as a reference to guide the final design scheme of the mobile exhibition space of the community's art gallery in the subsequent design process.

IV. DESIGN PRACTICE AND EVALUATION

The results of this study show that the symbiosis of design should be the core in the design of the mobile exhibition hall of the community art gallery, including the key design element of sustainability; Secondly, the brightness sense of the mobile exhibition space should be paid attention, which mainly includes three design elements: wide, bright and interesting; Finally, it is still necessary to take the freshness reflection of the mobile exhibition space into account, which mainly covers three elements: natural, simple and diverse. In this study, the weight analysis is analyzed on six design components of the mobile exhibition hall space (namely, exhibition wall, exhibition tools, ceiling, lighting, corridor and guide table) through the users' emotion mapping model established by QFD. After calculation, the highest weight sub-components of various components are: exhibition wall 3, exhibition tool 3, ceiling 4, lighting 4, corridor 1 and guide table 2.

1) DESIGN PRACTICE

The exhibition wall is arranged around the exhibition hall in the form of a detachable wall pattern, which facilitates the division of different exhibition Spaces. At the same time, through the comprehensive use of recycled waste wood, it visually creates an emotional feeling of circulation and symbiosis. Structured see-through walls render the bright and wide sense of the space by avoiding blocking the view of the space. The display adopts the form of a rotating geometric screen, which drives the change of spatial pattern to enhance

FIGURE 9. Display of the design scheme effect.

the diversity and interest of the space. The ceiling adopts the combination mode of bare structure and geometric lighting arrangement to highlight the core focus of the exhibition hall in a simple form, so that people's eye can focus on the core parts of the exhibition. The form of the corridor is unified with the overall space of the exhibition hall. While taking on parts of the exhibition function, it combines geometry with natural materials and matches with the outdoor landscape, highlighting the natural symbiotic atmosphere of the space. The simple form of the guide table is placed at the end of the corridor and the entrance of the exhibition hall, connecting from the front to the end, thus forming a simple transitional gray space.

The overall design runs through the principle of detachable and easy installation. In order to make the exhibition mode of the space meet the emotional needs of users, it can be adjusted appropriately and flexibly used in different community Spaces according to actual needs. The details of the design scheme are shown in Figure 9.

2) EVALUATION OF DESIGN PRACTICE

In order to verify the objectivity of the design scheme and the suitability between the scheme and the emotional needs of the target users, the fuzzy comprehensive evaluation method is used to evaluate the design scheme, which can solve many complex problems in the evaluation process such as fuzziness and diversity of elements. In this stage, 15 target users are invited to evaluate the emotional image of the design scheme of the mobile exhibition hall of the community's art gallery mentioned above.x=(u_1, u_2, u_3) is used to represent the factor set of the evaluation index of emotional image

TABLE 17. Description of evaluation index and weight value.

Evaluation index	Description of evaluation index	Collection of comments	Evaluation index weight
A_1	freshness	Very suitable (v_1)	0.09
A_2	brightness	Relatively suitable (v_2)	0.33
A_3	symbiosis	generally suitable (v_3)	0.59
		Completely unsuitable (v_4)	

elements, and u_1, u_2, u_3 represents the sense of freshness, brightness and symbiosis respectively.

The users' comments set adopts v=(v_1, v_2, v_3, v_4) for corresponding Settings, and the corresponding standards are specified, that is, v_1, v_2, v_3, v_4 correspond to the four levels of very suitable, relatively suitable, not very suitable, completely unsuitable; Secondly, the comments set are assigned to different level and the comments vector $\alpha = (90, 80, 60, 40)^T$ is obtained. The score division interval corresponding to the four levels is: ''very suitable'' corresponds to more than 90 points, ''relatively suitable'' corresponds to 80 90 points, ''not very suitable'' corresponds to 60 80 points, ''completely unsuitable'' corresponds to less than 60 points; According to the calculation results of the above AHP hierarchical analysis, the weight vector of the criterion layer is $w_A = (0.09, 0.33, 0.59)$,which can be seen in table 17 for details.

In the process of establishing the fuzzy comprehensive evaluation matrix, the matrix of criterion layer A is named q;15 target users are invited to score and evaluate the criterion layer. Finally, the calculation results of the fuzzy comprehensive evaluation matrix corresponding to each criterion layer can be obtained. The specific results are shown in Equation (18):

$$q = \begin{Bmatrix} 0.33 & 0.4 & 0.27 & 0 \\ 0.53 & 0.33 & 0.13 & 0 \\ 0.67 & 0.27 & 0.07 & 0 \end{Bmatrix} \tag{18}$$

The weight value of emotion factor calculated by AHP is combined with the result of fuzzy set evaluation matrix, and the criterion layer fuzzy evaluation result of the design scheme can be calculated according to equation (19). The specific calculation result of comprehensive evaluation weight vector is shown in Equation (20):

$$p = w \times q \tag{19}$$

$$p = w_A \times q \tag{20}$$

In the process of percentage evaluation and calculation of the design scheme, the calculation results are shown in equation (21):

$$N = w_A \times \alpha = 83.78 \tag{21}$$

Therefore, the overall scheme's final score of the mobile exhibition hall in the community's art gallery is 83.78; the information analysis of the design scheme's satisfaction is shown in table 18.

TABLE 18. Satisfaction of design scheme.

Evaluation index	Design scheme of mobile exhibition hall	
	Satisfaction degree	Comprehensive satisfaction degree
A_1	59.20	
A_2	30.00	83.78
A_3	10.70	

V. DISCUSSION

The collection of emotional images is the basis of constructing the research framework of KE. SD usually evaluates semantic vocabulary by means of questionnaire survey and so on. SD can obtain clear emotional image, but subjective judgment is often difficult to guarantee the objectivity of survey results. Although physiological measurement can guarantee the objectivity of test data through instrument detection, the results displayed only include the strength of the subject's emotional image, and lack the description of the specific emotional connotation. Compared with the two kinds of emotional images' collection methods mentioned above, Web crawler can finally get the most representative connotation of users' emotional image through objective statistical calculation, through changing the search conditions of the program and in combination of subjective and objective conditions, occurrence frequency and other screening factors. Table 19 shows the specific comparison of the above methods in the part of acquiring emotional image.

The computational analysis of emotional image is the core of KE' s research process. The quantitative linear analysis represented by GRA and MRA is usually suitable for calculating and analyzing the correlation degree between emotion image and comprehensive design features, but it is difficult to establish the factor correlation structure divided by multiple levels. With the development of artificial intelligence technology, ANN and other related technologies have been widely used in interdisciplinary research in humanities, social sciences, medicine and other multidisciplinary fields, which can carry out parametric analysis and processing of specified information by simulating the model of human brain neurons. However, ANN cannot fully guarantee the accuracy behind decision logic. Moreover, the target object similar to the research object cannot be detected, which also leads to high quality requirements for a large amount of data in the research process. Compared with the above methods, the highly representative analytic hierarchy Process (AHP) in the index weighting method not only has the advantage of identifying the structural relationship of multi-level factor division, but also can solve the classification problem of approximate factors. The comparison of the above methods is shown in the section of emotional image calculation in Table 20.

TABLE 19. Comparison of research methods to capture emotional images.

Research perspective	Research method	explanation	advantages	limitations
Acquisition of emotional images	Semantic Differential	According to the subjective feelings of the users, the semantic vocabulary of the target object is evaluated and the data is analyzed by statistical methods.	No auxiliary instrument is required, with clear emotional images , simple data analysis and short analysis cycle.	Strong subjectivity, with a certain uncertainty.
	Physiometry	The physiological changes triggered by emotion are measured by instrument.	The emotional reactions experienced by decision makers can be reflected objectively.	The measurement method has limitations; the feedback results can not show the specific emotional contents.
	Web crawler	The relevant emotional information is retrieved and collected by modifying the program.	It can retrieve a large amount of information with high retrieval efficiency.	some subjectivity about the search conditions is needed.

TABLE 20. Comparison of computational analysis method of emotional images.

Research perspective	Research method	explanation	advantages	limitations
Calculation of emotional images.	Index weighting method	According to the relative importance analysis among the factors, the relationship among the factors is determined, which mainly includes AHP, TOPSIS, Delphi method, and so on.	The emotional expectations of decision-makers can be directly reflected.	The subjectivity in the process of investigation is strong.
	GRA	According to the similarity degree of development trend among the factors, the correlation among the factors is determined.	The demand for data analysis quantity is small.	The analysis process lacks the correlation analysis of various features under the comprehensive features.
	Multivariate Regression Analysis MRA.	Analyze the change law of a certain phenomenon with the change of factors.	The degree of correlation and regression fit among factors can be accurately calculated.	The analysis process lacks the correlation analysis of various features under the comprehensive features.
	Artificial Neural Network ANN.	Simulate human brain neurons to analyze relevant information and focus on dealing with nonlinear relationship problems.	It has high precision, which can achieve accurate output of hidden data input.	The computation is huge, and the black box network has low interpretability.

Under the research framework of KE, it is the key to construct the mapping model between users' emotional images and design elements to guide the generation of design schemes. In previous studies, TRIZ theory has been widely used in products' optimization and iteration in order to use contradiction matrix analysis to deal with the conflict between products' function principle and technology, thus continuously generating innovative products which are close to the ideal development path. However, TRIZ theory is difficult to fully coordinate the contradiction between users' needs and designers' subjective judgment. Therefore, it is difficult to realize and popularize the optimized products to meet the emotional needs of users. With the continuous development of information technology, SG and other theories have been promoted to analyze and improve the products' shape specifications on the basis of mining a large number of existing form patterns, thus building a complete form law to guide products' optimization design. However, in SG's analysis, it is also difficult to explain the shape and connotation of the products. Compared with the above model mapping methods, QFD's quality function expansion has the advantage of taking users' needs as the leading role, quantifying users' needs and design elements. At the same time, in the optimization process of designing parts, it can make the parts cover the emotional connotation of users. Table 21 shows the comparison and analysis between QFD and the two types of methods mentioned above in the mapping between emotional images and design elements.

VI. CONCLUSION

This studies combines Web crawler with EFA and AHP to get the users' emotional images and the calculation results together with the morphological deconstruction conclusion of Delphi are put into the QFD model mapping analysis under the framework of KE research. The above research methods can effectively obtain the form optimization mode of spatial components that meet the emotional expectations of users. Additionally, the relevant morphological features adhere to the modular combination model, facilitating assembly and

TABLE 21. Comparison of methods for constructing mapping model.

Research perspective	Research method	explanation	advantages	limitations
Mapping between emotional image and design elements.	QFD	The emotional quantification data is combined with design elements and value evaluation to get a plan that meets the needs of users.	It has a strong pertinence to users' needs.	The calculation amount is large and the scheme generation cycle is long.
	TRIZ	A solution approximating the ideal solution is obtained by referring to the ideal path.	The process is simple and the high quality innovative products can be obtained.	The subjective factors of designers are large in the design process.
	SG	Based on shape prototype and shape rules, a complete set of formal rules is defined.	The output of the scheme is large.	There are strict requirements on the premise of program analysis and the products' form context needs to be formed.

disassembly with recyclable waste wood materials. This approach aims to achieve design objectives focused on ease of disassembly and assembly. This design strategy can maximize the use rate of the art gallery in different spaces, greatly reduce the material consumption in the process of setting up the gallery, and ultimately validate the possibility of "movable" components of the community art gallery. From the satisfaction of the users' emotions to the appearance of the morphological design, it effectively promotes the sustainable development of the community art gallery's mobile exhibition halls.The main contributions of this paper include:

1) The KE-based study of mobile galleries in community art museums has verified the possibility of guiding the sustainable transformation of the community's art gallery's forms with the help of users' emotional needs through a combination of qualitative and quantitative approaches.
2) Web crawler and Delphi respectively reduce parts of subjective judgment factors in the collecting stage of Kansei words and the deconstruction stage of component forms.
3) The modular assembly mode of space components is easy to disassemble and install, which improves the mobility of the exhibition space and effectively improves the resource consumption of the spacel.
4) The application of recyclable waste wood provides the possibility of recycling the space components of the mobile exhibition hall, thus creating a sustainable space environment.

There are still several limitations in this paper that need to be further improved:

1) Sustainable design should not only consider space configuration, component form and so on, but can form a complete comprehensive development system by combining service system to comprehensively solve the problem of sustainable development in space.
2) There are still many subjective judgment factors in the KE research system, which focuses on the analysis of users' emotion, so there may be some deviation between the research results and the actual complex factors. It is suggested that such problems can be improved by combining physiological measurement methods and artificial intelligence algorithms in the future.
3) In this paper, only the realizable form mode of the mobile exhibition hall at the visual level is put forward, but there is no discussion on the details of specific components' engineering assembly. In the future study, the structural model which are more suitable for engineering implementation should be taken into consideration from the perspective of engineering implementation.

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