An Innovative Application of Diagonal Ridge Elements of Classical Suzhou-style Buildings to Furniture Design Based on Kansei Engineering and Shape Grammar

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This paper proposes a furniture design method combining Kansei engineering (KE) and shape grammar (SG), to explore how the diagonal ridge elements of classical Suzhou-style buildings can be applied to furniture design and to explain how the styling elements match the cultural imagery in furniture products. Suzhou-style armchairs and cultural elements of diagonal ridges were collected, the most suitable armchairs were selected for incorporating such elements, and their shapes were deconstructed along with characteristic interpretations. A factor bank of diagonal ridge elements was constructed, first through Kansei word selection and evaluation experiments, and then through factor analysis which determined the main cultural elements of the design. The shape grammar theory was applied to design and innovate the selected armchair samples, achieving three design solutions. The solutions were then comprehensively evaluated, and the optimal one was used for the final physical product. The results of the study showed that users had clear subjective feelings about the design incorporating diagonal ridge elements, with their Kansei on three aspects: aesthetic style, decorative complexity, and structural balance. The approach used in this work blends furniture products with cultural imagery on diagonal ridges, providing a feasible methodological reference and an empirical case for cultural sustainability through furniture design.

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Keywords: Diagonal ridge elements; Kansei engineering; Shape grammar; Furniture design

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INTRODUCTION

As an important part of traditional Chinese furniture culture, Suzhou-style furniture carries rich historical and cultural values. This style of furniture has been studied from the aspects of historical background, Suzhou-style armchairs, varieties and shapes, deconstruction, fabrication methods, artistic aesthetics, and symbolic semantics, aiming at blending traditional Chinese furniture with modern design philosophy. For example, Pu (1999) delineated the boundary between Suzhou-style and Ming-style furniture by delving into the historical background of Suzhou furniture in the Ming and Qing dynasties and by substantially exemplifying the varieties, forms, and the late-stage evolution of Suzhou-style armchairs. Hu and Chandhasa (2023) further studied the construction of Suzhou-style armchairs and reproduced the rigorous fabrication process of Suzhou-style armchairs with an official's hat chair as a case study. Some have also delved into integrating the aesthetic demands of users into the design of the furniture, by recounting how, in the late Ming

Dynasty, literati framed furniture design concepts and artisans integrated them into fabrication (Xiao and Xue 2015; Jie and Xin 2017).

However, the urgent need for cultural sustainability and continuous improvement of the material living standards have given an added boost to people's pursuit of quality, aesthetics (Christian and Schumann 2020), and cultural elements of furniture products. Thus, in China the design of such products is evolving towards an integration of traditional Chinese culture. Despite the competitive advantages of Suzhou-style furniture in the Ming Dynasty, the traditional handicraft industry now faces dilemmas (Fan and Feng 2019). A key issue is, therefore, how to accurately match both styling elements and cultural imagery in furniture products (Xu and Pan 2023), establish communication between products and users, and accurately make furniture products. To address the above problems, researchers have tried to introduce Kansei engineering (KE) and shape grammar (SG) in furniture product design, illuminating how practical and innovative they are in the fusion of traditional Chinese culture with modern designs of Chinese armchairs, Arhat beds (a Chinese type of bed with a low back and sides), and Ming-style stools.

Kansei engineering (KE) is a method that translates consumers' affective needs and preferences into specific design parameters (Nagamachi 1986, 1995, 1997). By studying the target users' affective responses to products (Chen *et al*. 2015; Li *et al*. 2021), such as emotions, feelings, and intuition, KE quantifies these subjective feelings (Huo *et al*. 2023) into design indexes. Such indexes guide the product design process, thus stronger attraction and higher market competitiveness of products (Barravecchia *et al*. 2020). Many scholars have employed KE in the study of furniture design. For example, Zhang (2019) conducted a symbolic semantics study on Suzhou-style furniture, in which she established the relationship between functions of furniture design and symbolic affective semantics. Liu *et al*. (2021) explored the intrinsic connection between Kansei imagery and shape design elements of Ming-style Luohan beds, providing a methodological basis for quantifying the Kansei imagery embedded in shape design features of traditional furniture. Lin *et al*. (2024) performed Kansei semantics experiments on Ming-type, Qing-type, and modern Chinese-style furniture, whereby they found that consumers considered the Qing-type furniture more ornate and personalized, and modern Chinese-style furniture more modern and streamlined. An *et al*. (2022) finalized the style of screens by quantitatively studying the Kansei images and linear patterns of traditional Chinese wooden screens. Moreover, Zhou *et al*. (2023) combined user perception with grey correlation analysis, in an effort to establish a scientific and effective design method. KE bridges the gap between consumers' affective experience and product design, so that the design process is not only based on technical and functional needs, but also on affective needs (Nagamachi 1995; Coronado *et al*. 2020).

Shape Grammar (SG) is a design reasoning method that focuses on shape operations. Originally proposed by Stiny and Gips (1971), who applied it to painting and sculpture and then defined by Stiny (1980), SG has extended to innovative visual and product designs (Hsiao and Chen 1997; Lee and Tang 2009; Ang *et al*. 2013; Wortmann and Stouffs 2018; Mata *et al*. 2019; El-Mahdy 2022). The core concept of SG is to find out the hidden rules of shape composition and then streamline and refine this shape, so that the new graphs creatively retain the characteristics of the original (Cui and Tang 2013). Hence, scholars have also availed of shape grammar (SG) in furniture design. For instance, Xue and Chen (2024) integrated, with the help of SG, new cultural elements from other fields and realized the cross-field integration of wooden architecture and wooden furniture, demonstrating the possibility and practicality of cultural crossover and sustainability. In a study on Chinese stools, Qu *et al*. (2023) proposed an integrated way of design and evaluation that combined SG, KANO model, and entropy weighting, shedding light on how to integrate regional cultural symbols into the design of Chinese furniture. Also using SG, Fu *et al*. (2022) incorporated elements of Jiangxi Exorcism Masks into their self-established bank of stool elements, thus upgrading the original design. Moreover, combining SG with eye-movement technology, Zhao *et al*. (2023) extracted elements of cultural imagery of Tibetan Duomu Kettles and applied the elements to furniture product design, paving the way for blending ethnic artifacts with modern furniture design. Furthermore, based on SG and other methods, Yu (2023) achieved digital sustainability of the intangible cultural heritage of the "Wu Leno" (silk fabric with a light texture) weaving technique in Suzhou.

The above studies have deeply explored the symbolic semantics and Kansei imagery of traditional furniture. Utilizing methods such as SG and KE, these studies have provided rich theoretical and practical approaches to, or implications for, traditional Chinese furniture design, and they have made cultural crossover and innovative integration more possible. While the existing studies promote furniture design, there have been relatively few studies on the integration of architectural elements into furniture product design. The present study therefore makes this attempt.

Using KE and SG, this study elaborates on how diagonal ridge elements of classical Suzhou-style buildings can be fused into the design of armchairs. This is first because armchairs are a common piece of furniture in these buildings and second, the buildings are a quintessential part of the globally renowned, culture-loaded, and sublimely crafted classical Suzhou gardens (a UNESCO Intangible Cultural Heritage Site)—a microcosm of the natural world, incorporating such basic elements as water, stones, plants, and various types of buildings of literary and poetic significance. Transplanting the culture-loaded diagonal ridge elements into armchairs will therefore help to bring the culture alive, and this innovative product design may well cater to users.

EXPERIMENTAL

Research Process

The whole study involved four stages.

Stage 1: Before the research, the specific subject was defined and the methods were determined. Next, samples of cultural motifs on diagonal ridges of classical Suzhou-style buildings and types of Suzhou-style armchairs were systematically collected and analyzed. This process involved extensive literature review and fieldwork to ensure the diversity and representativeness of the samples. Then, a questionnaire was designed and distributed. Finally, teachers of design and furniture design practitioners gathered opinions to select the most suitable armchair carriers for incorporating elements of the motifs. This stage laid the foundation for subsequent design and development.

Stage 2: The diagonal ridge motifs obtained from the field research were screened and produced into collections of stimulus samples. These collections were used in subsequent KE studies to assess the visual and affective impacts of different design elements. In addition, this phase also included the collection and screening of Kansei words to extract, from relevant literature and expert interviews, key terms describing the affective impact of diagonal ridge elements. Following that, experiments on Kansei semantic evaluation were conducted, and factor analysis methods were used to process the experimental data, so as to identify the design elements that can most touch users' Kansei.

A comprehensive factor bank was built, accordingly.

Stage 3: Based on SG, key elements were extracted from the factor bank, and in-depth logical derivation of these elements was carried out. This process involved reinterpretation and application of traditional cultural elements through modern design methods, to ensure that the design solutions reflect the cultural characteristics of the diagonal ridges and meet the aesthetic and functional needs of modern furniture. Ultimately, these theoretical derivations and design practices were combined to form innovative furniture design solutions.

Stage 4: The final stage of the study focused on assessing the Kansei needs of the new designs and on verifying their market acceptance. A semantic differential scale was employed for target users to evaluate the affective responses of the design solutions. Based on the assessment results, the design solution with the best feedback was selected for refinement, and subsequently, a physical model was fabricated. The research process framework is shown in Fig. 1.

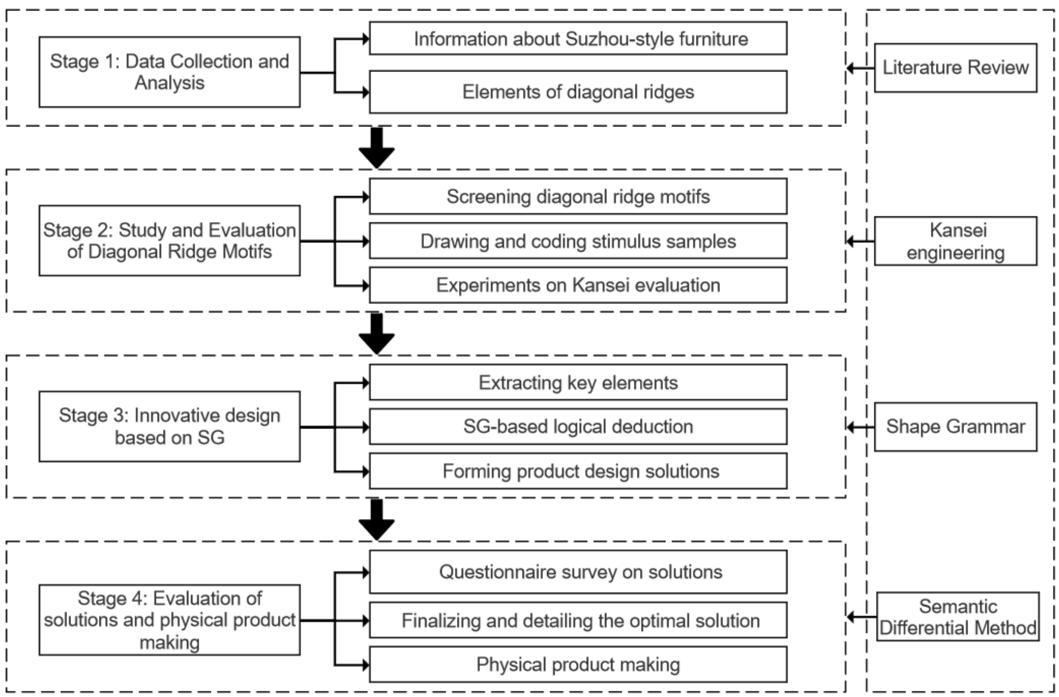


Fig. 1. The research process framework

Data Collection and Analysis

Diagonal ridge elements

Classical Suzhou-style buildings are featured by well-shaped high roofs, unique South-Yangze-River gatehouse style, and winding layout, thus creating a sense of implicit beauty (Ma 2018). On the roofs, there are diagonal ridges, which are the upturned part of the flying eaves. On such ridges, skilled craftsmen would make important, bizarrely shaped decorations of animals and/ or plants, for the sake of good luck. The diagonal ridge is made of stacked bricks and tiles (Fig. 2), categorized into the simple *Shuiqiang Faqiang* (gradually upturned diagonal ridge without a corner sub-ridge) and the complex *Nenqiang Faqiang* (steeply upturned diagonal ridge with a corner sub-ridge diagonally supported by a main corner ridge) by the different practices of wood-structure diagonal corner (Hou and Hou 2014).

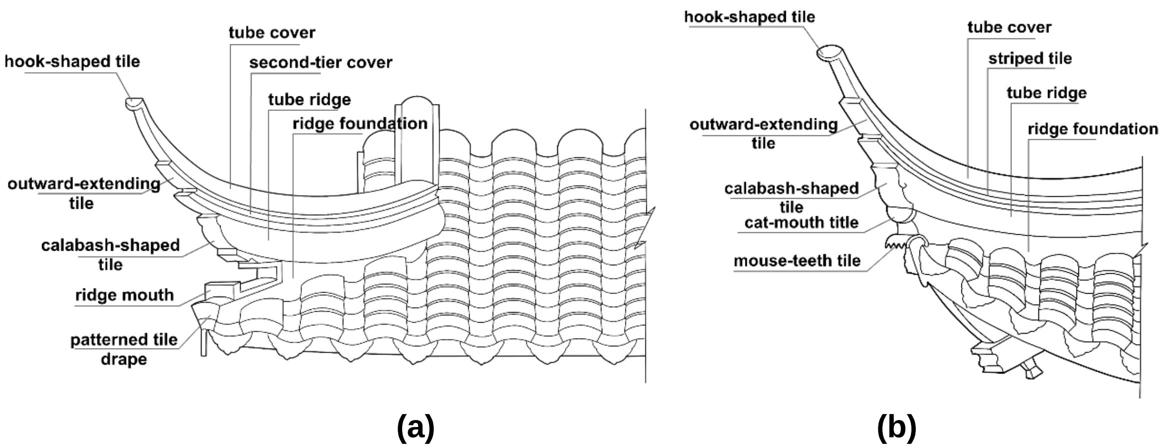


Fig. 2. (a) Deconstruction of *Shuiqiang Faqiang* and (b) *Nenqiang Faqiang*

Suzhou-style furniture

According to *The National Intangible Cultural Heritage List of China* (Zhang 2007), Suzhou-style furniture is defined as furniture delicately made of hardwood such as sandalwood (*Pterocarpus santalinus*), Huanghuali (*D. hainanensis*), and Jichimu (*Millettia laurentii, Senna siamea,* and *Millettia leucantha* Kurz) by skilled craftsmen in Suzhou and the neighboring South-Yangze-River regions after the middle of the Ming Dynasty. For accuracy and rationality, this study explicitly defines this style of furniture as armchairs with distinctive Suzhou characteristics in Ming and Qing dynasties, excluding the late Qing furniture varieties influenced by the Cantonese and Western styles (Mazurkewich 2016). According to Pu (1999), Suzhou-style furniture can be divided into seven categories: armchairs, stools, large tables (*zhuo*), small tables (*ji*), beds, cupboards, and screen frames. At different stages of historical development, furniture from all over the Ming and Qing dynasties, influenced by environment, conditions, customs, and lifestyle, showed a wide range of varieties and forms. In particular, the Suzhou-style chair can, according to functional and structural characteristics, be divided into two categories: armchairs and backrest chairs. The armchair category is further divided into: official's hat (Yoke-back Armchairs with Protruding Ends or "Guanmaoyi"), literati, rose, straight back, horseshoe back, hook-headed back, pen shaft, and screen back; the backrest chairs include lamp hanger, single-back, pen-stem, and screen-back types (Mazurkewich 2016). This means that Suzhou-style armchairs fall into twelve subcategories in total.

To select the most suitable chair carrier for diagonal ridge elements, a questionnaire was distributed to design faculty members and furniture design practitioners, of whom four had been in the profession for 5 to 10 years, and six for over 10 years. The subjects were asked to score how each sub-category matched the structural characteristics of diagonal ridge elements. Results showed that the most suitable one for cultural integration was the highest-scoring "official's hat" (Fig. 3).

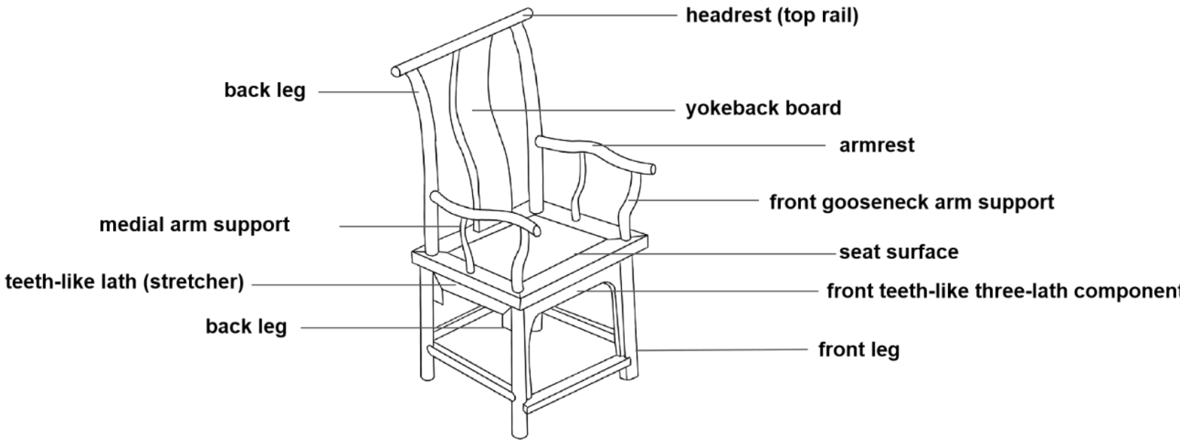


Fig. 3. Deconstruction of "official's hat" armchair

RESULTS AND DISCUSSION

Drawing and Coding Stimulus Samples

For diverse patterns and fine details of ridge elements, a survey team systemically photographed diagonal ridge elements at garden sites in Suzhou. The photographs were precisely outlined by drawing software, to clarify the outlines and characteristics of each structure. The photographs and the drawings were then categorized and numbered according to four types—assemblage, plant, animal, and artifact—to establish a bank of stimulus samples (Fig. 4).

Experiments on Kansei Evaluation

Selecting Kansei words

Adjective pairs were collected both online and offline. Literature on Suzhou-style armchairs (journals and e-books *etc*.) were accessed online; experts and scholars in this profession were interviewed offline. The adjective pairs were first screened and permutated, and a total of 30 groups of related words were collected. Then, a questionnaire about evaluating representative samples of Suzhou-style armchairs using Kansei words was filled out by ten experts. After that, the frequencies of the words chosen by the experts were sequenced, and semantically similar ones were deleted. Finally, six groups of vocabulary were obtained: ancient *vs.* modern; elegant *vs.* vulgar; complex *vs.* streamlined; symmetrical *vs.* asymmetrical; ornate *vs.* plain; and delicate *vs.* slapdash.

Questionnaire design and evaluation

Many analytical studies on KE have used the 5-point "Kansei" scale (Tama *et al*. 2015; Zuo and Yang 2020; Hsiao and Chen 2020; Chen 2023; Du *et al*. 2024), with each group of Kansei at the two sides. The closer the score is to 0, the weaker the semantic strength is, and conversely, the higher the score is, the stronger the semantic strength is. Take "ancient *vs.* modern" for example. "-2" refers to "very much ancient", "-1" to "quite ancient", "0" to "neither ancient nor modern", "1" to "quite modern', and "2" to "very much modern".

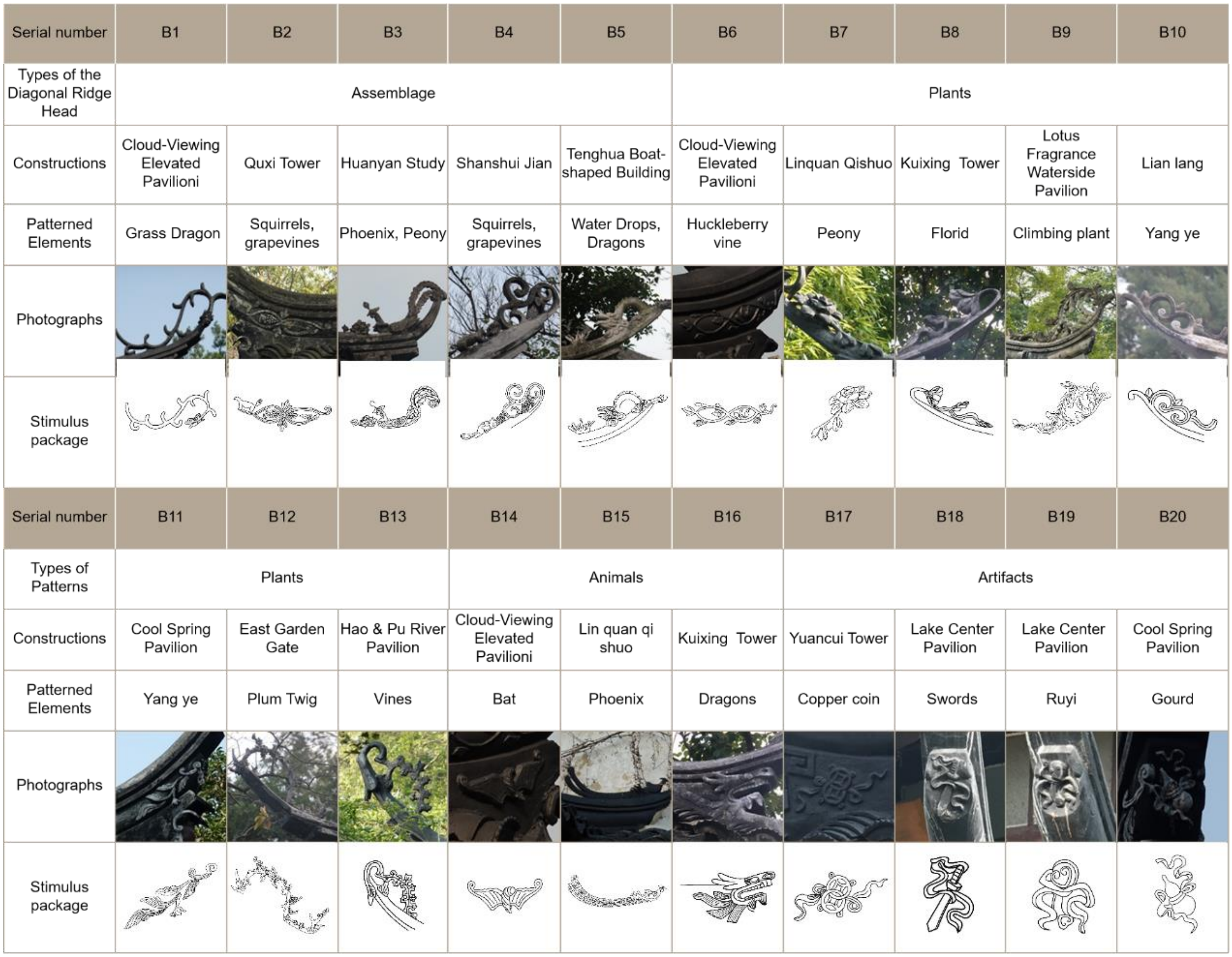


Fig. 4. Stimulus sample chart and their serial numbers

Due to the highly specialized content of the questionnaire and the large volume of the survey (consisting of 20 samples that each contains 6 questions, totaling 120 decision points), participants were likely to feel agitated or exhausted during the answering process. For the quality of questionnaire responses, the number of questionnaires distributed was controlled within a reasonable range. At the same time, to ensure prudent responses, raise the return rate, and improve the accuracy of the valid questionnaires, the respondents were provided with sufficient time to answer the questionnaires, and when necessary, with professional assistance. Considering the need to express Kansei words for chair products, the authors selected the survey respondents based on the following criteria. First, those who gave constant attention to furniture shopping platforms or offline furniture shops and had purchased furniture products in the last six months; second, those who had at least a four-year college education, to ensure that they can, to some extent, understand and appreciate furniture design, materials, technology, and graphic patterns; third, those who mainly lived in or around urban areas, since they had a unique aesthetic concept and were also the main buyers of furniture products. As a result, the participants were 5 design teachers, 5 designers, and 30 buyers of Chinese furniture. A total of 40 questionnaires were distributed, 34 valid questionnaires were returned (return rate=85%), and a cumulative total of 4,080 ratings were obtained.

Mean value statistics

SPSS software was used to analyze the mean values of the valid ratings on the 20 samples, and the results are shown in Table 1.

Most perceptual evaluations of B1 and B20 were significantly oriented towards “ancient and streamlined”; B2 towards “elegant”; B3, B4, and B13 towards “complex and asymmetrical”; B5 towards “ancient and asymmetrical”; B6 towards “symmetrical and plain”; B7 towards “elegant and delicate”; B8 and B19 towards “ancient and plain”; B9 towards “elegant and asymmetrical”; B10 towards “delicate and simple”; B11 towards “delicate”; B12 towards “complex”; B14 towards “symmetrical and streamlined”; B15 and B17 towards “ancient”; B16 and B18 towards “ancient and slapdash”. The above analysis revealed that “ancient”, “elegant”, and “plain” were the common characteristics of some of the samples, which can provide some reference for furniture design.

Table 1. Mean Values of Kansei Words

serial No.	Kansei Adjective Pairs					
	ancient *vs.* modern	elegant *vs.* vulgar	complex *vs.* streamlined	symmetrical *vs.* asymmetrical	ornate *vs.* plain	delicate *vs.* slapdash
B1	-0.76	-0.44	0.65	0.18	0.44	-0.53
B2	-0.68	-0.76	-0.65	-0.24	-0.35	-0.59
B3	-0.38	-0.35	-0.56	0.41	-0.44	-0.53
B4	-0.85	-0.59	-1	0.35	-0.74	-0.38
B5	-0.97	-0.5	-0.62	0.32	-0.21	0.21
B6	-0.56	-0.62	0.06	-1.38	0.21	-0.82
B7	-0.62	-0.82	-0.12	-0.06	-0.47	-0.82
B8	-1.09	-0.59	0.06	0.06	0.09	-0.82
B9	-1	-1.26	-1.06	0.12	-1.09	-1.06
B10	-0.41	-0.5	0.5	-0.18	0.15	-0.59
B11	-0.79	-0.76	-0.74	-0.18	-0.5	-0.82
B12	-0.82	-0.65	-1.09	-0.24	-0.71	-0.59
B13	-0.03	0.09	-0.18	0.53	0.26	0.12
B14	0.03	0.06	0.38	-0.91	0.32	-0.18
B15	-1.29	-1.24	-1.03	-0.03	-1.03	-1
B16	-0.74	-0.09	-0.29	0.21	-0.35	0.68
B17	-1.09	-0.62	-0.12	-0.71	-0.41	-0.38
B18	-0.38	-0.12	0.32	-0.24	0.18	0.56
B19	-0.18	-0.03	-0.09	-0.12	0.32	0.21
B20	-0.76	-0.5	0.29	-0.06	0.26	-0.41
Note: “0” is the median point; the greater the distance between the ratings and 0 is, the closer the participants' subjective perception of the samples is to the meanings conveyed by the Kansei words.						

A calculation of the absolute value of the difference between the mean and the median 0 of Kansei adjective pairs led to their extreme difference values. The larger the value of the extreme difference, the closer the subjective feeling to the Kansei words. Patterned samples corresponding to the absolute extreme difference value of each pair were selected as the cultural elements for this design scheme. As shown in Table 2, the frequency of the maximum difference corresponding to B9 was relatively high, while the frequency of the minimum difference corresponding to the B13 sample was relatively high. To ensure the diversity of the design elements, B6, B9, B12, and B15, which had the largest absolute values of the maximum difference, were finally selected. Since perceptions of these four were more in line with the corresponding words, they were selected as the cultural elements of this design.

Table 2. Absolute Values

Kansei words	The absolute value of the maximum difference	The absolute value of the minimal difference	Sample No.
Ancient *vs.* modern	1.29	0.03	b15/b13, b14
Elegant *vs.* vulgar	1.26	0.03	b9/b19
Complex *vs.* streamlined	1.09	0.06	b12/b6
Symmetrical *vs.* Asymmetrical	1.38	0.03	b6/b15
Ornate *vs.* plain	1.09	0.09	b9/b8
Delicate *vs.* slapdash	1.06	0.12	b9/13

Factor analysis

To further experimentally derive users' Kansei cognition of the samples, an exploratory factor analysis of the mean values of Kansei words was made using SPSS software. KMO and Bartlett's test results yielded a KMO value of 0.637 (>0.6), indicating that the correlation between the data is strong and can be factor-analyzed. Through principal component analysis, three main factors were extracted with eigenvalues of 3.439, 1.345, and 0.601, respectively, and their corresponding explained variance ratios were 57.309%, 22.419%, and 10.011%. The total contribution of these three factors reached 89.74% (Table 3). The results showed little loss in the interpretation of the raw data, showing that the main information of the 6 pairs of Kansei words can be better reflected by utilizing these three common factors.

Three pairs of Kansei words – "ancient *vs.* modern", "delicate *vs.* slapdash", and "elegant *vs.* vulgar"—had large loadings on factor 1, indicating great explanatory power of factor 1 on the variables represented by these three pairs. From the perspective of modeling design, factor 1 was named "the Aesthetic Style Factor" based on the meaning of the variables. Factor 2 consisted of two pairs— "complex *vs.* streamlined" and "ornate *vs.* plain"—and was named "the Decorative Complexity Factor". Factor 3 consisted of one pair— "symmetrical *vs.* asymmetrical"—and was named "the Structural Balance Factor".

Establishing a Factor Bank of Diagonal Ridge Elements

According to Table 2, the perceptions of B6, B9, B12, and B15 samples were more in line with the corresponding Kansei words, and therefore they were selected as the cultural elements for extraction and interpretation. Since the complicated diagonal ridge elements could not be directly applied to this design, representative patterns of each target element were deconstructed in the early stage, and a factor bank of diagonal ridge elements was set up (Fig. 5).

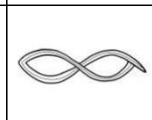
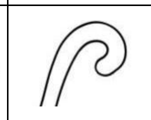
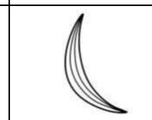
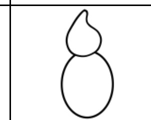
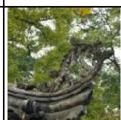
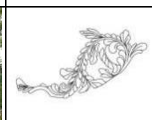
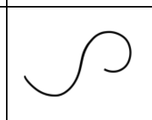
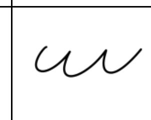
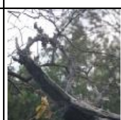
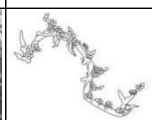
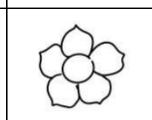
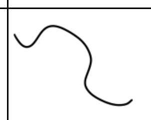
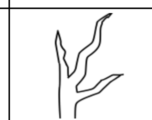
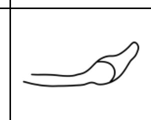
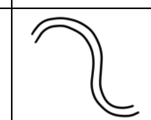
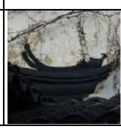
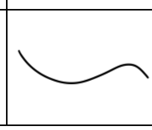
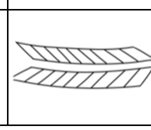
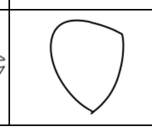
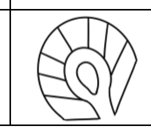
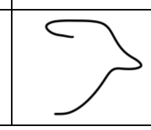
Table 3. Explained Variance Ratios

Factor No.	Characteristic Roots			Pre-rotation Explained Variance Ratio			Pre-rotation Explained Variance Ratio		
	Characteristic roots	variance (%)	cumulative%	characteristic roots	variance%	cumulative%	characteristic roots	variance%	cumulative%
1	3.439	**57.309**	57.309	3.439	57.309	57.309	2.333	38.878	38.878
2	1.345	**22.419**	79.729	1.345	22.419	79.729	1.965	32.752	71.63
3	0.601	**10.011**	89.74	0.601	10.011	89.74	1.087	18.11	89.74
4	0.467	7.78	97.52	-	-	-	-	-	-
5	0.097	1.621	99.141	-	-	-	-	-	-
6	0.052	0.859	100	-	-	-	-	-	-

Table 4. Post-Rotation Factor Loading Coefficients

Kansei Word Pairs	Factor Loading Coefficients			Common Factor Variance
	Factor 1	Factor 2	Factor 3	
ancient *vs.* modern	**0.778**	0.307	-0.244	0.76
complex *vs.* streamlined	0.199	**0.947**	-0.151	0.959
symmetrical *vs.* asymmetrical	0.062	-0.163	**0.956**	0.945
ornate *vs.* plain	0.423	**0.872**	-0.118	0.952
delicate *vs.* slapdash	**0.849**	0.116	0.271	0.808
elegant *vs.* vulgar	**0.885**	0.417	0.05	0.96

Table 5. The Factor Bank of Diagonal Ridge Elements

Serial No.	B6	C1	C5	C6	C7	C8	C9
Extracted Lines							
Serial No.	B9	C2	C10	C11	C12	C13	C14
Extracted Lines							
Serial No.	B12	C3	C15	C16	C17	C18	C19
Extracted Lines							
Serial No.	B15	C4	C20	C21	C22	C23	C24
Extracted Lines							

Innovative Grammatical Interpretation

As defined by Stiny and Gips (1972), SG can be expressed as follows,

$$SG = (S, L, R, I) \quad (1)$$

where S represents a finite set of shapes, SG denotes the set of derived shapes obtained through translation, rotation and mirroring, L is a finite set of markers, R refers to a finite set of inference rules, and I is the initial shape. Generative rules cover two basic operations: R1 for substitution, R2a for addition and R2b for deletion; derivative rules cover six basic operations: R3 for scaling, R4 for mirroring, R5 for copying, R6 for rotating, R7 for miscutting, and R8 for changing coordinates (Deng *et al.* 2021).

Considering the Kansei words of “ancient”, “elegant”, and “plain”, this study selected elements in the factor bank and transferred them to the official’s hat chair. Drawing software was used to carry out innovative SG derivation, which fell into two parts. The first part was the evolution and reorganization of the elements, and the second part was the solutions of how to apply the reconstructed elements on the carrier. D1, for example, was generated after rotating (R6), copying (R5), mirroring (R4), and stretching (R8) C6. The whole derivation steps are shown in Table 6.

The following are the derivation steps of Solution 1.

For the front view. Step 1: enter C6, execute R4 and R5 to duplicate and then mirror for symmetry, and then execute R1 to replace the headrest (top rail). Step 2: input C24, execute R2b and R8 to delete the unwanted parts and stretch them to fit the carrier; execute R4 and R1 to mirror and replace the front tooth-like three-lath component. Step 3: enter D1, D2, and D3 for combination, execute R2a to place the combination on the backboard. Step 4: input D4, execute R5 to copy and arrange R2b, delete the overflow to get a new pattern, and execute R2a to place it on the backboard.

Table 6. New Element Derivation Steps

Basic Factors	Evolution Process	Newly Derived Elements	Basic Factor	Evolution Process	Newly Derived Elements
C6	R6 → R4+R5+R8 →	D1	C12	R8 → R2b → R4+R5+R8 →	D5
C6	R6+R8 → R4+R5 →	D2	C15	R2b+R8 → R4+R5 → R3+R5+R8 → R1+R4+R5+R8 →	D6
C6	R2b+R6 → R4+R5+R8 →	D3	C6	R2b+R6 → R8 →	D7
C11	R8 → R5 → R5 →	D4			

For the side view. Enter D7, execute R2b to delete the elements to adapt them to the carrier, and then execute R1 to replace the medial arm support.

For the top view. Step 1: enter C19, execute R8 to stretch the elements to fit the carrier, execute R5, R4 and R1 to mirror for symmetry and replace the armrests. Step 2: enter C9, execute R8 to stretch the element to fit the carrier, and then execute R5, R4, and R1 to mirror the symmetry and replace the front part of the armrest.

Derivation steps of the front view of Solution 2 were as follows. Step 1: enter D5, execute R5 and R4 for a mirror copy, and then execute R1 to replace the headrest. Step 2: input D6, execute R2a to place D6 on the backboard, and then execute R2b to delete the backboard. Step 3: enter C9, execute R4 and R8 for a new pattern, and execute R2a to place it on the backboard. Step 4: enter C6, execute R5, R4, and R1 to mirror for symmetry, and replace the front tooth-like three-lath component.

Derivation steps for the side view Solution 3 were as follows. Following Deng *et al*. (2021), C10, C20 and C16 were obtained by extracting the characteristic lines of factors C2, C4 and C3. Step 1: input C20, execute R8 for stretching, and execute R2b to delete the teeth-like lath, and then execute R1 to replace the seat surface and backboard. Step 2: enter C10, execute R8 for stretching, execute R2b to delete medial arm support, and then execute R1 to replace the armrest. Step 3: enter C16, execute R8 for stretch, and then execute R1 to replace the teeth-like lath (stretcher). Step 4: execute R3 and R8 to scale and stretch the parts for a more aesthetically pleasing shape, and execute R2a to add a connector between the seating surface and the teeth-like lath to make it more practically stable. The second part of the derivation process in which the reconstructed elements were applied to the carrier is shown in Fig. 5.

Evaluating the Design

Figure 5 shows the modeling and the renderings of the three armchairs, which need to be evaluated separately for the optimal solution that meets consumer demand and caters to the market (Stiny 1980). A 5-point semantic differential scale was used to conduct a questionnaire survey on the perceptual needs of the innovative designs of the official hat chair. All groups of Kansei adjectives were at the two ends of the scales, where the closer a score is to 0, the weaker the semantic strength is, and the farther, the higher. The questionnaire was distributed to 5 design teachers, 5 designers, and 30 consumers of Chinese furniture. With a return rate of 95%, the response data were calculated and the results are shown in Table 7. The results showed that the overall scores of all solutions were positive, thus all being valid. The average scores of solution 1, 2, and 3 were 0.68, 0.45, and 0.37, respectively. Solution 1 scored the highest and was therefore finalized.

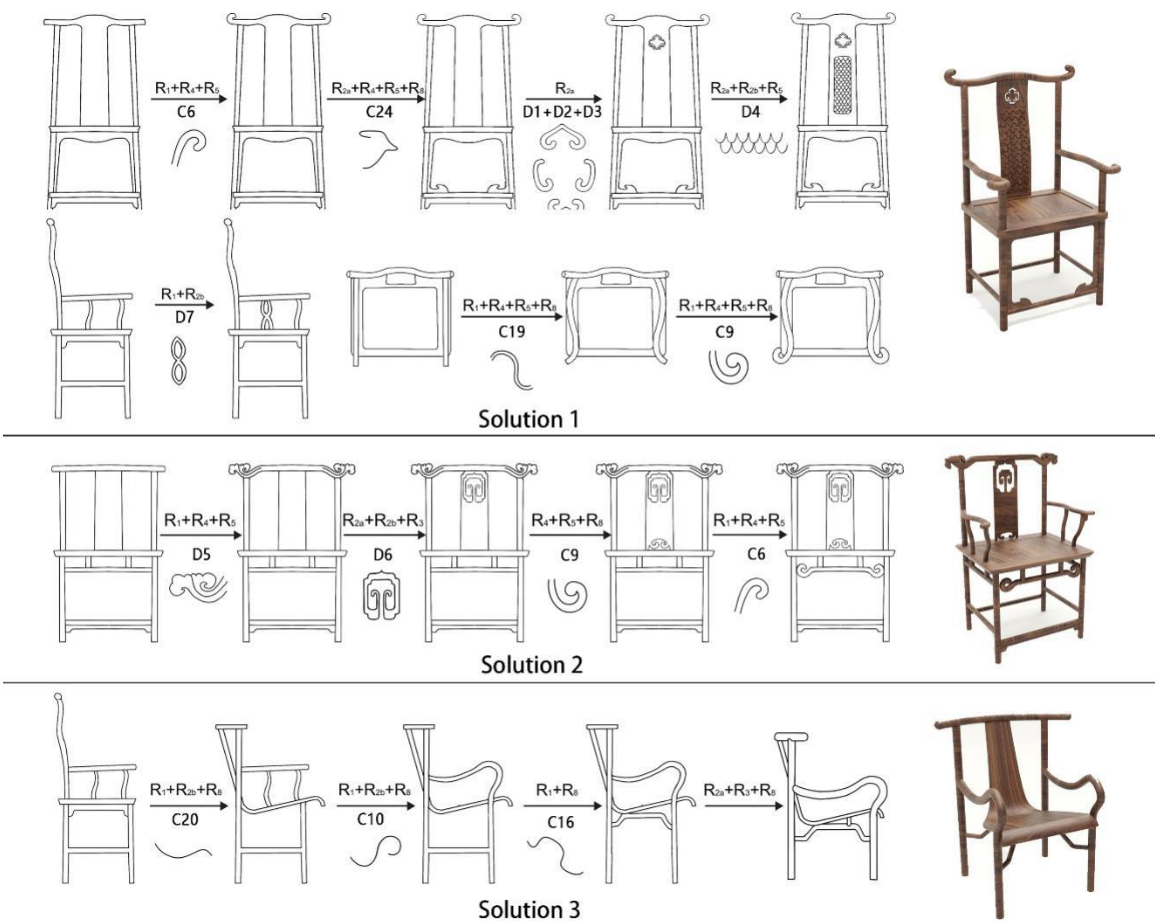


Fig. 5. Derivation steps for the three solutions

Table 7. Comprehensive Evaluation Results

Serial No.	Adjectives Group	Solution 1	Solution 2	Solution 3
1	ancient *vs.* modern	1.34	1.26	0.03
2	elegant *vs.* vulgar	0.97	0.76	0.53
3	streamlined *vs.* complex	1	0.37	1.16
4	ornate *vs.* plain	-0.29	-0.24	-0.5
5	delicate *vs.* slapdash	0.37	0.08	0.63
	overall rating	0.68	0.45	0.37

Refining the Solution

During refinement, meticulous attention was paid to the connection among the structural components, and the proportion of the details was made more in line with the physical chair. KeyShot 2023 software was to simulate the material and rendering (Fig. 5). Hard, dark-brown walnut wood was used, for the sake of delicateness and steadiness of the diagonal ridge elements in the architectural culture. In the process of fabrication, the ergonomic relationship of the chair was considered in accordance with the national standards. The final product was a traditional Suzhou-style official's hat chair blending modern aesthetics with traditional Chinese diagonal ridge culture.

Fig. 6. Rendering of the final product

Fabricating the Product

According to the rendering, dark-brown walnut wood was chosen for fabrication. Hard and durable, this type of wood also has a beautiful texture. Large pieces of wood were cut into various parts, shaped, carved, and sanded. Then the full set of parts were assembled, fixed, and lacquered for beauty and protection. Finally, each detail was double-checked. The following are pictures of the fabrication process and the physical model (Fig. 7).

Fig. 7. Fabrication process and the physical model

DISCUSSION

In this study, the application of the diagonal ridge elements of Suzhou-style buildings to furniture design using Kansei engineering (KE) and shape grammar (SG) provided an effective combination of cultural elements and modern design. Combining traditional cultural elements with consumers' affective needs, this study created a furniture product both of cultural value and of modern aesthetics, providing practical, cultural, and empirical values for the sustainability of cultural heritage.

This study is, to some extent, similar to An *et al*.'s (2022) research which analyzed the cultural elements of wooden screens based on KE and emphasized the role of cultural elements in enhancing the affective value of products. Different from their study, this study further utilizes SG not only to analyze the affective impact of cultural elements, but also to guide specifically the design process, providing a more comprehensive framework from theory to practical application.

This study also has something similar to Lin *et al*.'s (2024) KE-based exploration into how different styles of solid wood furniture impact consumer perceptions. While their study focused on the quantification of user perception by Kansei vocabulary, this study not only analyzed the Kansei factors but also innovatively applied design elements incorporating SG. The uniqueness of this study in synthesizing and applying two theories to product design can match users' affective needs and cultural expectations more accurately.

Though similar to previous studies that have emphasized the importance of cultural elements in product design, this study differs from them methodologically, *i.e.* this study uses SG to apply cultural elements directly in design practice rather than just perceptual evaluations. For example, Deng *et al*. (2021) used a combination of SG and cultural imagery to design the appearance of subway trains, which is methodologically similar to this study, but they did not use KE for their analysis and focused mainly on large-scale industrial products. Contrarily, this study focuses on furniture, a product category that, closer to everyday life and personal use, allows for a more nuanced and personalized application of cultural elements.

These comparisons and contrasts show that this study has a clear advantage in using SG and KE to intersect traditional cultural elements and modern design needs. Such an approach not only enhances the cultural depth of the design, but also improves the market appeal of the furniture products, showing the new value and sustainable life of traditional cultural heritage elements in modern design.

CONCLUSIONS

1. This study combined chair design using the diagonal ridge elements of Suzhou-style architecture with users' perceptual imagery, creating a furniture product that has traditional features and meets the needs of modern life. By collecting, evaluating, and identifying the samples of Suzhou-style chairs, this study selected a carrier most suitable for integrating with the diagonal ridge elements and then carried out structural deconstruction and analysis. Perceptual evaluations were then performed on the collected stimulus pictures of cultural imagery of the diagonal ridge elements, thereby determining the design elements as well as discovering the perceptual factors affecting the diagonal ridge elements (the "Aesthetic Style Factor", the "Decorative Complexity

Factor", and the "Structural Balance Factor"). After that, a factor bank of ridge elements was built, and the elements were deconstructed, derived, and reconstructed following SG rules. The elements were finally applied to Suzhzou-style furniture.

2. There are two merits of this design. For one thing, the design aimed at users' affective needs, meeting their needs for the cultural imagery of the chair; for another, no matter how many times the cultural factors are innovatively iterated, they can still inherit the design elements of the official's hat chair. With the help of SG, this study blends new cultural elements from Suzhou-style constructions, achieving cross-sectoral integration of Suzhou-style architecture and furniture and thereby making cultural crossover and sustainability more practical. In summary, the application of KE and SG not only makes the design methodologically rigorous, but also satisfies the affective needs of users. This study is therefore crucial to the diversified needs of the market, user satisfaction, and sustainable inheritance of culture in the furniture design industry.
3. Despite the merits, the design still has two limitations. First, due to the highly professionalized content, large volume of questions, and rigorous sampling criteria, this design only selected a moderate sample size. Future studies may expand the sample size and diversity, to enhance the universality and applicability of the research findings. Second, shape grammar is a two-dimensional texture method and guides the design process through a series of predefined rules, which may, to a certain extent, limit designers' three-dimensional innovation and may lead to the homogenization of the designs if designers follow the rules too rigidly. As a remedy, future research may explore the integration of SG and AIGC for innovation and the derivation of three-dimensional forms. Such a combination not only overcomes current methodological limitations, but also inspires innovative designs and improves their diversity and uniqueness. In the field of application, the combined methods of KE and SG can be extended to other types of furniture design and even other design fields to verify their versatility and practicality. For example, the methods can be applied to home furnishings, automobile design, footwear, and clothing products, *etc.* to explore their adaptability and effectiveness in different design fields.

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