A Study on the Translation of Exterior Design for Tourist Trains Based on Affective Engineering and AHP

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Abstract. Purpose To promote standardized design for the exteriors of sightseeing trains.Methods This study uses Kansei image analysis and the Analytic Hierarchy Process (AHP) to establish a cultural feature database, and applies shape grammar to transform cultural features into design language.Results A design framework of "Kansei image extraction–cultural feature weighting–shape grammar translation–scheme evaluation" is proposed, providing a systematic approach for regional culture-oriented tourism sightseeing train exterior design.

Keywords: Kansei Image; Analytic Hierarchy Process (AHP); Shape Grammar; Tourism Sightseeing Train; Tianshui Culture

1 Introduction

Tourist trains integrate transportation, tourism, and regional culture. To avoid superficial symbol superimposition in exterior design, this study takes Tianshui culture as the context and combines Kansei image analysis, AHP, and shape grammar to extract cultural semantics, determine feature weights, and translate them into train exterior patterns.[1-3]

2 Research Paradigm and Methodological Framework Construction

With the rapid development of global tourism, sightseeing tourist trains have become an important travel mode. Most sightseeing trains currently adopt a "transportation + tourism + culture" model, enhancing travel experiences through themed routes and immersive services.

Existing studies mainly focus on functional optimization, user experience, CMF design, sustainable materials, and cultural symbol integration in train design [4–12]. However, systematic methods for extracting regional cultural semantics and transforming them into train exterior design are still limited.

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Taking Silk Road culture as the design background, this study proposes a corresponding research framework.

2.1 Research Methods

This study adopts Kansei image analysis to transform users' perceptions of regional culture into quantifiable semantic factors for sightseeing train exterior design. Previous studies have shown that Kansei Engineering is effective in cultural imagery extraction and aesthetic semantic analysis [13–14], providing methodological support for this research.In addition, the Analytic Hierarchy Process (AHP) was used to evaluate the importance of regional cultural characteristics and design elements. Existing studies indicate that AHP effectively supports cultural gene extraction and design decision-making [15–17].

Based on the results of Kansei analysis and AHP evaluation, shape grammar was further applied to generate and transform the train exterior form.

2.2 Methodological Framework and Technical Route

Against the background of Silk Road culture, this study takes Tianshui culture as the design context and proposes a research framework of "cultural feature extraction — symbol transformation — exterior application — design evaluation." The study aims to solve the problems of insufficient cultural symbolism and limited theoretical support in sightseeing train exterior design.

As shown in Figure 1, the process includes five steps:

(1) Collect visual samples and establish a cultural semantic vocabulary database.

(2) Screen Kansei vocabulary and construct semantic word pairs with the SD scale.

(3) Conduct AHP analysis and establish a cultural feature database.

(4) Apply shape grammar to generate design schemes considering exterior zoning and manufacturing constraints.

(5) Evaluate and optimize the design through SD scale analysis and expert reviews.

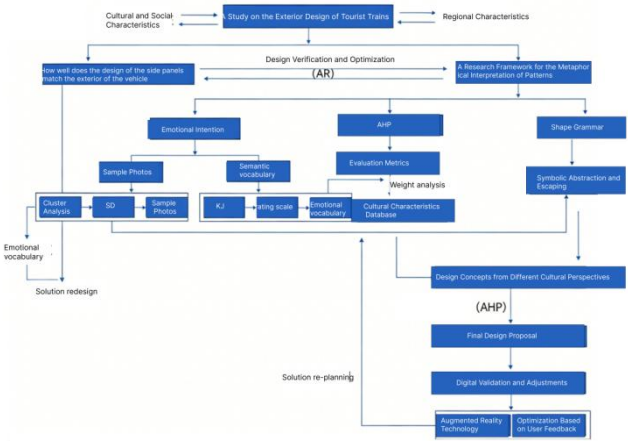

Fig. 1. Research Framework

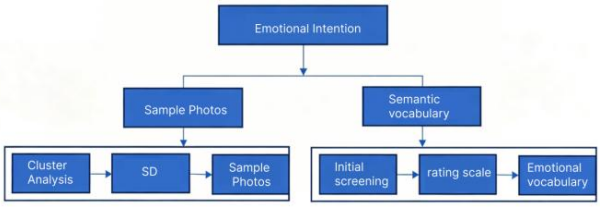

Fig. 2. Sensory Imagery Method Process

3 Cultural Element Extraction and Cultural Database Construction

3.1 Selection and Analysis of Cultural Imagery Based on Tianshui Culture

This study takes Tianshui culture as the design context and proposes a framework for sightseeing train exterior design. Cultural imagery samples were collected and standardized, and cultural elements were transformed into "graphic pattern units" for subsequent SD analysis, AHP calculation, and shape grammar generation. The workflow is shown in Figure 2. Regional culture was divided into three dimensions: traditional patterns, natural landscapes, and folk customs. Through field investigation and online collection, 90 sample images were obtained, with 30 images selected for each dimension. All images were uniformly processed using Adobe Photoshop to reduce evaluation interference.

A focus group consisting of two industrial designers and three industrial engineering students further screened the samples using the KJ method, excluding samples with unclear regional characteristics or low abstraction potential.

3.2 Screening and Extraction of Kansei Vocabulary

Through website research, promotional materials, interviews with tourists and local residents, and questionnaire surveys, this study collected 200 emotional terms related to Tianshui culture. Based on these findings, a focus group was organized to screen the terms and integrate their meanings. Ultimately, this study selected 40 representative pairs of emotional semantic terms for subsequent SD scale construction and semantic analysis, as shown in Table 1.

Table 1. Sets of affective semantic terms identified in the initial screening.

Number	Semantic Vocabulary	Number	Semantic vocabulary	LNumber	Semantic vocabulary	Number	Semantic vocabulary
1	Massive	11	Tranquility	21	Symmetrical	31	Central Heraldry
2	Antique	12	Peace	22	Orderly	32	Sense of Order
3	Solemn	13	Zen	23	Stable	33	Plain

4	Time-honored	14	Compassion	24	Structural	34	Implicit
5	Composed	15	Buddhism	25	Extensive	35	Down-to-earth
6	Majestic	16	Ethereal	26	Open	336	Introverted
7	Sense of History	17	Sacred	27	Three-dimensional	37	Warm
8	Elegant	18	Order	28	Majestic	38	Honest
9	Diverse	19	Balance	29	Interconnected	39	Symmetrical
10	Integrated	20	Layering	30	Layered	40	Totemic

3.3 Kansei Cultural Analysis Based on the SD Method

After identifying the affective semantic terms, this study adopted a 7-point Likert scale to evaluate semantic similarity. A pairwise comparison rating method was then used to assess the semantic relationships among the lexical terms, and the average scores were calculated to obtain the similarity matrix. The data were subsequently imported into IBM SPSS Statistics for cluster analysis.

Average Value Formula:

$$S_{ij} = \frac{1}{n} \sum_{k=1}^{n} S_{ij}^{(k)} \tag{1}$$

Where i and j represent different vocabulary terms, n represents the number of evaluators, and $S_{ij}^{(k)}$ represents the score given by the k-th evaluator.as shown in Fig 3.

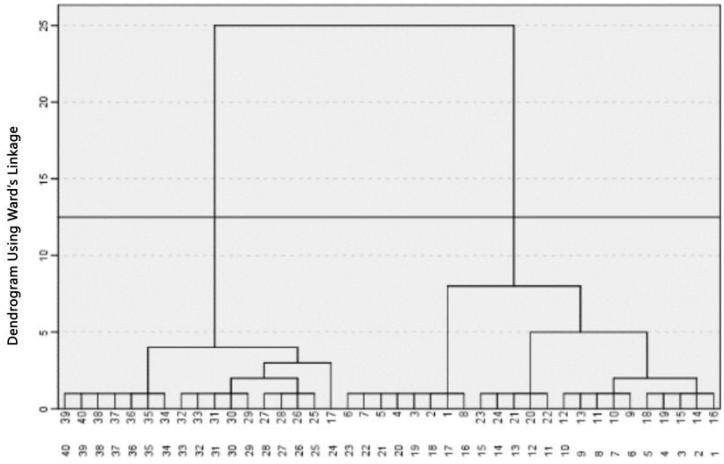

Fig. 3. Family Tree

to provide a foundation for subsequent AHP application.

3.4 Construction of a Cultural Feature Database Based on AHP

Establishment of the Evaluation Index System. Following an affective cultural analysis based on SD, this study identified the affective semantic characteristics of Tianshui culture. However, these results do not clearly reflect the relative importance of each cultural characteristic in the design process. Therefore, this study further introduced the Analytic Hierarchy Process (AHP) to calculate the weights.

(Six graduate students majoring in design were invited to conduct pairwise comparisons of the importance of each cultural trait. The evaluation results are shown in Table 2.)

Table 2. AHP Decision Matrix.

	Substantial	elegant	sacred	orderly	layered	totemic	unadorned
Substantia	1	3	1	2	3	5	4
elegant	1/3	1	1/2	1/2	2	3	2
sacred	1	2	1	2	3	5	4
orderly	1/2	2	1/2	1	2	4	3
layered	1/3	1/2	1/3	1/2	1	3	2
totemic	1/5	1/3	1/5	1/4	1/3	1	1/2
unadorned	1/4	11/2	1/4	1/3	1/2	2	2

Construction of the Judgment Matrix for Sub-Indicators. For each sub-indicator in the evaluation system, a pairwise comparison judgment matrixA=(a_{ij})where a_{ij}represents the importance of indicator i relative to indicator j.The study adopted the 1–9 scale method to quantify importance, where 1 indicates equal importance and 9 indicates extreme importance.

The judgment matrix was then normalized by dividing each element by the sum of its column, resulting in the normalized matrix:

$$b_{ij}=\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}(\mathrm{i, j=1, 2, ..., n}) \tag{2}$$

The study then calculated the geometric mean of each row in the normalized matrix

$$\bar{w}_i=\sqrt[n]{\Pi_{i=1}^{n} a_{ij}}; \quad w_i=\frac{\bar{w}_i}{\sum \bar{w}_i} \tag{3}$$

The calculated weights of each indicator are as follows: w_1 =1.959, w_2 =0.864, w_3 =1.843, w_4 =1.218, w_5 =0.666, w_6 =0.289, w_7 =0.507(w_1 represents heaviness; w_2 represents elegance; w_3 represents sacredness; w_4 represents orderliness; $w_5$represents layering; $w_6$represents totemic quality; $w_7$represents simplicity)

3.5 Construction of a Cultural Feature Library

After determining the weights of Tianshui's core cultural characteristics, a cultural feature database was established. Following the logic of "cultural semantics—visual features—formal transformation," core semantic features were mapped to corresponding cultural samples. These features were then organized into four categories: cultural origins, semantic meanings, visual representations, and design transformations.As shown in Table 3, the resulting database integrates weighting results, semantic interpretation, visual characteristics, and formal mapping, providing a foundation for subsequent pattern generation and train exterior design.

Table 3. Cultural Characteristics Database.

Cultural Characteristics	Weight	Semantic Interpretation	Design Interpretation Direction
Substantial	0.265	Reflecting the rich historical heritage of Tianshui culture	Highlights a calm and sophisticated exterior style, suitable for the main visual area
elegant	0.116	The aesthetic charm and understated elegance that reflect regional culture	Used to reinforce the expression of the brand identity and core cultural symbols
sacred	0.247	Embodying religious significance, a sense of ritual, and spiritual symbolism	Used to enhance the overall aesthetic and cultural sophistication of the exterior
orderly	0.165	Reflecting structural order and formal regularity	Suitable for continuous patterns and sectioning along the vehicle's flanks
layered	0.099	A space that embodies the depth and historical legacy of Tianshui culture	Used to enrich the visual hierarchy and rhythm of the exterior
totemic	0.040	Reflecting the symbolic and distinctive elements of regional culture	Used to create localized branding and thematic patterns
unadorned	*0.068*	Reflecting the local way of life and the authenticity of nature	Used to balance the decorative intensity of the overall exterior and avoid excessive complexity

Thus, the Tianshui cultural feature library enables the quantitative screening of cultural semantics.

4 Shape Grammar-Based Derivation Mode

4.1 Shape Grammar-Based Reasoning Rules

To ensure the feasibility of pattern generation, this study selected typical visual samples of Tianshui culture for pattern extraction. Guided by core semantics such as

"substantial," "sacred," and "elegant," the samples were deconstructed into outline frameworks, structural rhythms, and identifying details to extract transformable morphological features. Shape derivation rules were established by considering train exterior constraints, including uniqueness, continuity, and manufacturability.

The rules were classified into four categories: basic form extraction, abstraction, form generation, and application constraints. Basic form extraction generated the initial morphological unit S_0 ;abstraction rules unified the design language through geometrization and symbolization; form generation rules created patterns through symmetry, repetition, and hierarchy; and application constraint rules controlled the results according to train dimensions, manufacturing processes, and visual recognition requirements.

4.2 Mapping Rules Between Cultural Semantics and Formal Elements

Based on the AHP results, solemnity, sacredness, and elegance were identified as the core cultural features, while orderliness, layering, totemic symbolism, and simplicity served as auxiliary features. Accordingly, three pattern prototypes were constructed, and shape grammar was applied to generate differentiated pattern families from A1 to G3, as shown in Table 4.

Table 4. Pattern Design.

Cultural Characteristics	Abstract Form Characteristics	Pattern Design (Schematic)
Substantial	Substantial, low center of gravity	 (A_1) (A_2)
sacred	A Sense of Ceremony and a Clear Focal Point	(B_3)  (B_1)(B_2) 
elegant	Even rhythm, flowing curves	(C_3)  (C_1) (C_2) 
orderly	Clear structure with a strong sense of repetition	(D_3)  (D_1)(D_2) 
layered	Layering and Spatial Depth	(F_3)  (F_1)(F_2) 

totemic	Highly symbolic, central axis structure	(G_3) 	(G_1)(G_2) 
unadorned	Simple and natural, with ample white space	(H_3) 	(H_1)(H_2) 

4.3 Scheme Derivation Based on Train Exterior Zoning

Trains feature distinct structures and visual hierarchies, with exterior zones differing in recognizability, continuity and decorative performance. Thus, patterns shall be deployed systematically based on vehicle architecture instead of arbitrary surface superimposition.

Tourist trains are divided into core identification, continuous display and auxiliary functional zones by structure and visual needs. Differing in hierarchy, information capacity and viewing perspective, each zone requires exclusive pattern design..as shown in Fig 4 and Fig 5.

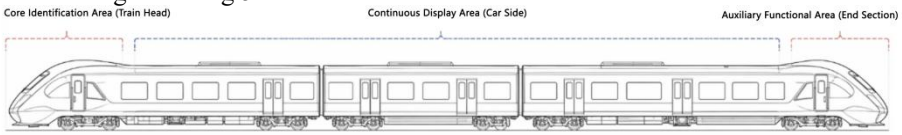

Fig. 4. Schematic of the partitions

Taking the Y671 train as an example, this study conducted an application design, as shown in Figure 5.

Fig. 5. Exterior Design for Train Y671

5 Conclusion

This study focuses on the design translation of Tianshui regional culture and proposes a framework including cultural semantic extraction, morphological mapping, shape grammar derivation, and pattern generation.As the study mainly emphasizes methodology and pattern generation, the application of the generated patterns to complete train exterior design still requires further exploration. Future research may

optimize these patterns through product design integration, CMF strategies, manufacturing constraints, and user evaluation.

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