Media and Communication Research (2025)
Clausius Scientific Press, Canada

DOI: 10.23977/mediacr.2025.060402
ISSN 2523-2584 Vol. 6 Num. 4

Research on the Application of Translation and Expression of Dunhuang Cultural Genes in the Design of Rail Trains

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Keywords: Rail vehicle shape design; Interior design; Dunhuang Cultural Gene; Analytic Hierarchy Process (AHP); Shape Grammar

Abstract: The research aims to apply the cultural genes of Dunhuang to the modern design of the exterior and interior of rail vehicles, in order to enhance their cultural recognition and regional value. Firstly, the cultural genes of Dunhuang are systematically screened and classified into explicit and implicit genes. The Analytic Hierarchy Process (AHP) is then used to calculate the weight values of each cultural factor. Secondly, the design focuses on the high-weighted shape factors and uses the rules of Shape Grammar to deduce them, corresponding, integrating and reorganizing them with the structural features of rail vehicles to form a new library of structural morphological features for rail vehicles. At the same time, the high-weighted color and semantic factors are applied to the design practice. Through the methodological path of cultural gene extraction, AHP weight calculation and Shape Grammar deduction, the innovative translation of Dunhuang cultural elements in the design of rail vehicles has been effectively achieved. The research results not only provide new ideas for the modern design application of Dunhuang regional culture, but also establish theoretical basis and practical references for the cultural expression of rail transit vehicles, enabling them to showcase their unique cultural charm in a global context.

1. Introduction

With the acceleration of urbanization, urban rail transit has developed rapidly as an important means to alleviate traffic congestion and enhance urban functions. With the rapid development of rail transit, more and more cities are paying attention to the integration of local culture, enhancing the cultural connotation and urban image of rail transit. This trend not only enhances the cultural experience of passengers, but also strengthens the cultural soft power of the city. Lu Honglei et al. [1] summarized the application ideas of regional culture in rail vehicle design through classic cases of rail vehicle design at home and abroad. Taking the application of Huizhou culture in rail vehicle design as an example, new symbols were applied to rail vehicle design. Xie Xuanhui [2] used the method of lineage analysis to conduct research on the evolution of urban rail transit vehicle design based on lineage analysis, using vehicles with typical characteristics as research samples. Qi Bailing et al. [3] proposed a subway vehicle styling design method that combines regional cultural symbols with biomimetic imagery. By extracting cultural elements and integrating local biological forms, biomimetic design is carried out. Qiao Zhihang et al. [4] compared and summarized the current situation of urban rail vehicle exterior design that integrates regional cultural characteristics at home and abroad, extracted typical cultural symbols and characteristic elements, screened concrete patterns and integrated them, and applied them to the exterior design of Hefei subway vehicles.

Based on this, this article will focus on the translation and expression path of cultural genes on rail trains, aiming to establish a systematic design logic for cultural genes and promote the innovative application and organic integration of regional culture in rail transit design.

2. Cultural gene theory

2.1. Concept of Cultural genes

The concept of cultural genes originates from the theoretical framework of genetic genes in biology. American anthropologists Alfred L Kroeber and Clyde Kluckhohn pointed out that the sustainable transmission of culture is because it depends on the inheritance of human cultural symbols [5]. The concept of Cultural Gene was proposed by Richard Dawkins in "The Selfish Gene", taken from the Greek root "Mimeme" and defined as "Meme". Similar to biological genes, Cultural Gene refers to the basic unit of cultural transmission, which can be inherited and evolved in social groups through imitation, transmission, and variation[6].

2.2. Research methods for cultural genes

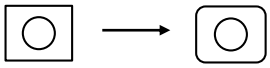
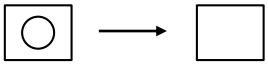
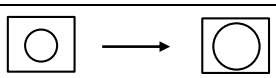
2.2.1. Semiotics analysis

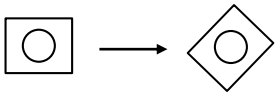
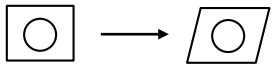
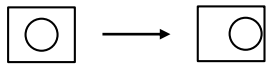
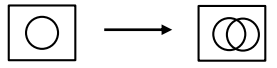
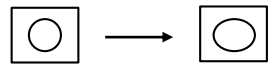
Semiotics is an interdisciplinary field that studies symbols and their meaning transmission, involving multiple disciplines such as linguistics, philosophy, psychology, cultural studies, and communication studies. Its core focus is on how symbols generate meaning and how humans understand and communicate through symbol systems. The basic unit of semiotics is "symbol", which consists of "signifier" and "signified", namely the referent and referent in language. The former represents the image represented by the symbol, while the latter represents the concept of the symbol. The two interact to form the symbol[7]. Semiotics involves the study of the generation, dissemination, interpretation, and influence of symbols, with the aim of gaining a deeper understanding of the importance of symbols in language, art, culture, and social communication[8].

2.2.2. Shape grammar inference

The shape grammar formula is expressed as SG=(S, L, R, I), where S represents a finite set of shapes; L represents a finite set of labels; R represents a finite set of inference rules; I represents the set of initial shapes; SG is a set of shapes formed through deduction operations such as addition, deletion, permutation, and scaling [9]. In practical applications, the derivation process of shape grammar is very important. The derivation process refers to gradually obtaining more complex shapes or designs from the initial shape by applying a series of rules. The deduction rules of shape grammar are shown in Table 1.

Table 1 Shape Grammar Inference Rules

	Characteristics of Rules	Rule Name	Method	Diagram
Generative rules	Focus on product form Hereditary inheritance, actual Replacement of current form disruptive innovation[10]	R1=Characteristics of Rules	Replace existing shape curves with partial shape curves	
		R2=Add/Delete	Add or delete some or all of the shape curves	
		R3=Zoom	Reduce or enlarge some or all of the curves	

Modified rules	Focus on product form Variation in appearance, resulting in Becoming a new form [10]	R4=Rotation	Transform the initial shape angle	
		R5=Miscutting	Shift the initial shape of the line segment proportionally	
		R6=Translation	Move the local nodes of the initial shape in a straight line	
		R7=Copy	Copy the initial shape	
		R8=Stretching	Stretch the initial shape	

3. Design process of rail train based on cultural gene

This study has established a systematic design process of rail train based on cultural gene, including three key stages, as shown in Figure 1.

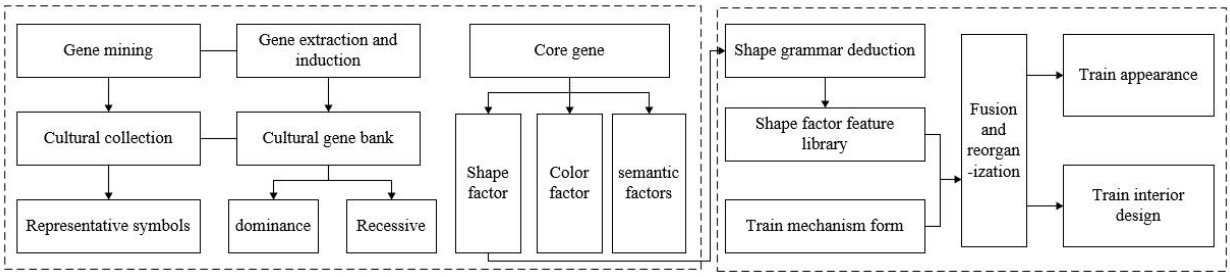


Figure 1 Design process

This study has established a systematic design process of rail train based on cultural gene, including three key stages, as shown in Figure 1. In the first stage, Dunhuang Cultural genes were extracted through semiotics. The representative cultural symbols of Dunhuang are excavated, the dominant factors are extracted and summarized by using the description method and geometric generalization method, and the recessive factors are extracted and summarized by using the symbolic method, so as to establish a cultural gene bank with clear classification. The analytic hierarchy process is used to establish the judgment matrix through expert review, calculate the weight value of each cultural factor, and screen out the high weight factor suitable for the design of rail train. In the second stage, shape grammar is used to translate the design. The selected shape factors are grammatically deduced to establish a morphological feature library, which is integrated and reorganized with the structural features of the train (lights, windshield, side windows, seats, etc.) to form a new design language. The third stage completes the design expression of the rail train. The design drawing is formed according to the morphological feature library and the size parameters of the rail train. At the same time, the high weight color factor and semantic factor are integrated into the design scheme to complete the transformation from cultural elements to design language. Using Likert scale to collect feedback from experts and users, the feasibility of the design was verified.

4. Screening of Dunhuang regional cultural genes

4.1. Exploration of Dunhuang cultural elements

Dunhuang is located in the northwest of Gansu Province, China, and is an important historical and cultural city at the western end of the Hexi Corridor, under the jurisdiction of Jiuquan City. As an important

node of the "the Belt and Road", Dunhuang has continued the legend of the intersection of eastern and western civilizations, and is a treasure house for exploring ancient Chinese history and multiculturalism [11]. The Mogao Grottoes culture is a typical representative of Dunhuang culture, and its murals, sculptures, and architectural styles are not only manifestations of religious beliefs, but also witnesses to cultural exchanges along the Silk Road. It is the largest and most diverse Buddhist art holy site in the world. Founded during the Sixteen Kingdoms period, it has undergone continuous construction during the Northern Dynasties, Sui and Tang Dynasties, Five Dynasties, Western Xia, Yuan Dynasties, and other dynasties. Currently, there are 735 caves, 45000 square meters of murals, and 2415 mud colored sculptures[12], vividly showcasing ancient Buddhist culture, the history of Sino Western exchanges, and the evolution of art over a thousand years. It is a treasure for studying the history, art, and religion of the Silk Road. By selecting Mogao Grottoes elements as design points, these profound cultural foundations can be transformed into modern design language, creating works with cultural depth and historical significance.

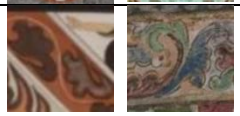
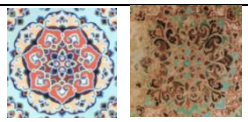
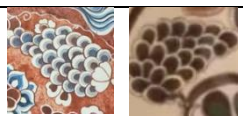
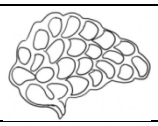
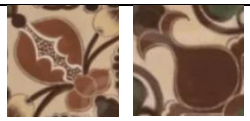
4.2. Extraction and induction of cultural factors

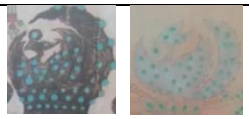
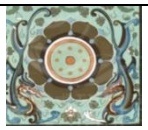
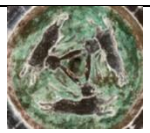
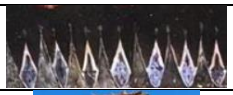
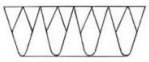
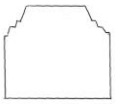
4.2.1. Extraction of explicit factors

The extraction of explicit factors is a key step in transforming specific and visible elements from Dunhuang culture into modern design language. These explicit factors mainly include visual elements such as form, color, etc. in Dunhuang art, which are the most intuitive and easily recognizable cultural features that can directly convey cultural information in design. The process of extracting explicit factors requires selecting the most representative and modern design elements from the rich artistic heritage of Dunhuang culture.

The classical patterns and architectural modeling elements of the Mogao Grottoes of Dunhuang are extracted and summarized, numbered B1-B14, as shown in Table 2.

Table 2. Summary of Styling Factors

Shape factor	Factor source	Factor prototype	Factor characteristic line
B1	lotus design		
B2	acanthus design		
B3	Baoxiang Pattern		
B4	Grape pattern		
B5	Pomegranate pattern		
B6	flying Apsaras		

B7	phoenix		
B8	Dragon pattern		
B9	Rabbit pattern		
B10	fret		
B11	Lianzhu pattern		
B12	Cloud pattern		
B13	Scale pattern		
B14	building		

Extract and summarize color elements from Dunhuang murals, numbered as C1 to C5, and extract feature lines, as shown in Table 3.

Table 3. Summary of Styling Factors

Color factor	Factor source	Factor prototype	Factor extraction	RGB
C1	red			R:194 G:94 B:52
C2	blue			R:87 G:89 B:164
C3	green			R:108 G:168 B:143
C4	yellow			R:189 G:159 B:117
C5	brown			R:131 G:88 B:57

4.2.2. Implicit factor extraction

The extraction of implicit factors helps to spread traditional cultural values and strengthen the cultural connotations of products. The semantics of symbols focus on the relationship between symbol form and symbol object, that is, the meaning of symbols or the information conveyed about symbols through symbol form. Therefore, comparing the cultural elements of Dunhuang region to a symbol, the ethnic spirit, local customs, and religious beliefs hidden behind the cultural elements will together form the semantic part of the pattern.

The patterns and architectural elements of Dunhuang not only have high artistic value, but also carry deep cultural and religious meanings. We need to summarize the semantics of the patterns in the aforementioned buildings and murals by categorizing them into three main groups, coded as D1-D3, as shown in Table 4.

Table 4. Semantic Factor Induction

semantic factors	Factor source	Factor significance	Factor extraction
D1	Dragon pattern, phoenix pattern, honeysuckle pattern, grape pattern	It reflects the intersection and integration of Eastern and Western cultures, symbolizing the fusion of Buddhist thought and local culture, and showcasing the diverse characteristics of cultural exchange along the Silk Road.	Cultural integration and harmony
D2	Lotus pattern, grape pattern, rabbit pattern, pomegranate pattern	Symbolizing the eternal and unchanging nature of life, it reflects the Buddhist concept of reincarnation and the endless continuation of life.	Vitality and Eternity
D3	Mogao Grottoes architecture (nine story, three story), flying patterns, lotus patterns	Symbolizing the gradual approach to Buddhism, wisdom, and enlightenment through practice, it embodies the spiritual concepts of "transcending reincarnation" and "upward sublimation" in Buddhism	Spirituality and Spiritual Pursuit

4.3. Cultural factor weights

4.3.1. Establishment of AHP weight model

The core of AHP model is to build a hierarchical structure, including target layer, criterion layer and scheme layer. In this study, the target layer is "Dunhuang regional culture", the criterion layer is dominant and recessive factors, and the scheme layer is specific cultural factors. The hierarchical structure model is shown in Figure 2.

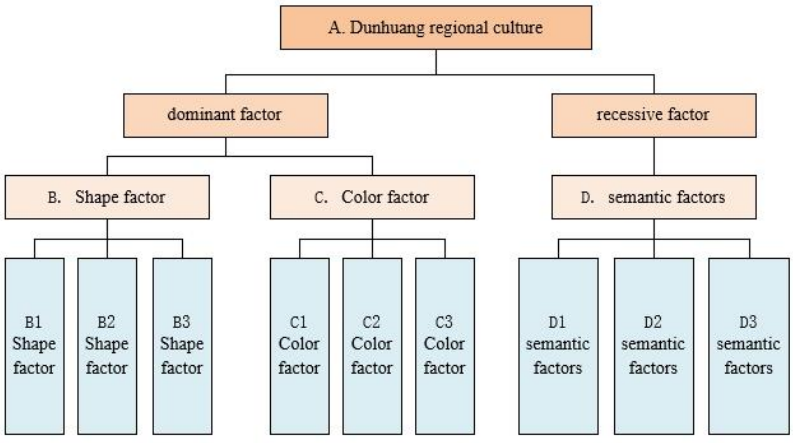


Figure 2. Structural model of cultural factors

4.3.2. Weight calculation of each indicator factor

The weights of each factor in the criterion layer should first be calculated. The criteria layer includes B styling factor, C color factor, and D semantic factor.

To determine factor weights within the criterion layer, thirty designers with more than two years of industrial design experience scored the importance of styling, color, and semantic factors according to the established scoring criteria. The resulting weights are presented in Table 5.

Table 5. Criteria layer weight

Indicator layer	Weight	
B Shape factor	0.558	λ max=3.018
C Color factor	0.320	CI=0.009
D Semantic factors	0.122	CR=0.0173

Due to CR<0.10, it indicates that the weight calculation of each factor in the indicator layer is reasonable, and the matrix has passed the consistency test and has good consistency [13]. This indicates that the importance ranking of Dunhuang regional cultural factors is reasonable and stable. Specifically, the importance of design categories to Dunhuang regional culture is ranked as follows: form>color>semantics, indicating that form occupies a more important position in the cultural genes of Dunhuang region.

4.3.3. Weight calculation of styling factors

After ranking the importance of each factor in the index layer, the importance of the 14 most important modeling factors B1 - B14 was quantitatively scored, and the weight of each modeling factor was calculated. The results are shown in Table 6.

Table 6. Weight of Styling Factors

	B1	B2	B3	B4	B5	B6	B7	B9	B10	B11	B12	B13	B14
Weight	0.041	0.167	0.026	0.033	0.048	0.066	0.046	0.054	0.087	0.056	0.088	0.020	0.119

The maximum eigenvalue λ max of the judgment matrix is calculated to be 14.511, and the consistency index CI is 0.0393.

According to the table, when n=14, the average random consistency index RI is 1.58. The random consistency ratio CR is 0.024.

Due to CR<0.10, it indicates that the weight calculation of the styling factor is reasonable, and the matrix has passed the consistency test and has good consistency. This indicates that the importance ranking of styling factors is reasonable and stable. Specifically, the styling factor B2 is the most important for the Dunhuang regional culture, followed by B8 and B14.

4.3.4. Color factor weight calculation

The same method is then used to quantify the importance of color factors C1-C5 and calculate the weight of each color factor. The results are shown in Table 7.

Table 7. Weights of Color Factor

	C1	C2	C3	C4	C5			
Weight	0.283	0.352	0.150	0.095	0.120	λ max=5.407	CI=0.1018	CR=0.0908

Due to CR<0.10, it indicates that the weight calculation of color factors is reasonable, and the matrix has passed the consistency test and has good consistency. This indicates that the importance ranking of color factors is reasonable and stable. Specifically, the importance of color to Dunhuang regional culture is ranked as follows: C2>C1>C3>C5>C4, indicating that C2 and C1 are the most important to Dunhuang regional culture.

4.3.5. Semantic factor weight calculation

Similarly, the weight calculation results for semantic factors D1-D3 are shown in Table 8.

Table 8. Weights of Semantic Factor

	D1	D2	D3			
Weight	0.685	0.221	0.094	λ max=3.055	CI=0.0275	CR=0.0529

Due to CR<0.10, it indicates that the weight calculation of semantic factors is reasonable, and the matrix has passed the consistency test and has good consistency. This indicates that the importance ranking of semantic factors is reasonable and stable. Specifically, the importance of semantic factors to Dunhuang regional culture is ranked as follows: D1>D2>D3, indicating that D1 is the most important factor for Dunhuang regional culture.

4.4. Result analysis

According to the above calculation results, it can be seen that the importance of styling factors is the highest, among which B2, B8, and B14 are the most representative styling factors; Among the color factors, C2 blue and C1 red can be used as the main design colors; The semantic factor D1 "cultural integration and harmony" can be reflected as the core spiritual feature of Dunhuang culture.

5. Construction of shape feature library based on shape grammar

5.1. Establishment of shape factor shape feature library

Selecting three key styling factors B2, B8, and B14 as the deduction objects, the detailed change rules are as follows:

I={  }

R={Generative rules, Modifiable rules}

According to the basic paradigm of shape grammar, first establish an initial shape set I={Ia, Ib, Ic}, where Ia corresponds to the characteristic contour line of B2, Ib represents the characteristic contour line of B8, and Ic represents the characteristic contour line of B14. The deduction rule set R includes two categories: generative rules and modifying rules, which are specifically subdivided into eight basic transformation forms: R1 permutation, R2 addition and deletion, R3 scaling, R4 rotation, etc. Each rule further distinguishes the application object through subscripts, such as R1a representing the permutation transformation implemented on the B2 shape factor. The deduction process strictly follows the formal rule definition of $\alpha \rightarrow \beta$, starting from the initial shape I and generating derivative forms through the orderly application of rule R. The transformed form adopts Ian's naming convention, where a identifies the original form factor category and n represents the transformation sequence number [14]. In specific implementation, eight types of rule transformations are applied to each initial shape factor (Ia, Ib, Ic), and after multiple rounds of iteration to generate a candidate solution library, five sets of optimal solutions are selected from the derived results of each shape factor, as shown in Figure 3.

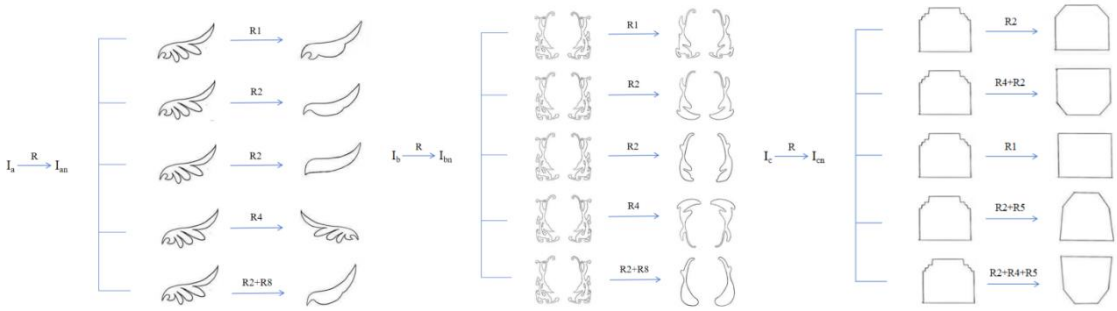
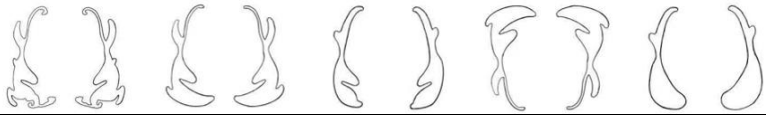
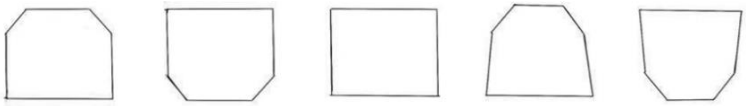


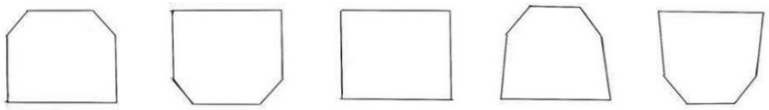
Figure 3. Shape factor form feature library

5.2. Corresponding construction of styling factors and rail trains

The basic styling elements of rail trains include key structures such as headlights, side windows, windshields, seat backrests, and seat side shields, which are prominent basic styling features in rail trains. By analyzing the various structures of the rail train, analogy can be used for mapping. In the exterior design of the subway, B2 can be compared to the shape of the car lights at the head of the subway, B8 to the shape of the side windows, and B14 to the shape of the windshield. In the interior seat design of the subway, B8 can be compared to the shape of the seat armrests, and B14 can be compared to the shape of the seat back [15]. Corresponding tables for morphological features exhibiting clear analogical relationships are established, forming a morphological feature mapping table as shown in Table 9.

Table 9. Weights of Semantic Factor

Group	Name	Illustration
Mapping Group 1	B2	
	Car light	
Mapping Group 2	B8	
	Side window	
Mapping Group 3	B14	
	Windscreen	
Mapping Group 4	B8	

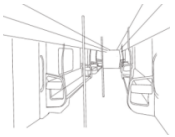
	Side panel	
Mapping Group 5	B14	
	Seat	

5.3. Extracting the morphological features of rail trains

Lanzhou is located in Gansu Province and is an important geographical and cultural hub of Dunhuang culture. The art and cultural heritage of Dunhuang have a profound impact on the history and culture of Lanzhou. Choosing Lanzhou Metro as the basis for renovation can better integrate Dunhuang cultural elements into daily travel environments. By combining Dunhuang culture with the design of Lanzhou Metro, it can strengthen the cultural identity of local residents in Lanzhou and provide tourists with a more distinctive transportation experience. This local characteristic design can also enhance the popularity and attractiveness of Lanzhou Metro both domestically and internationally.

Therefore, the shape and interior form of Lanzhou Metro Line 1 were adopted as the grammar rules for the shape of rail trains, and the morphological feature lines of Lanzhou Metro Line 1 were extracted, as shown in Tables 10.

Table 10. Characteristic Line of Subway Train Form

Train design image	Overall design	Car light	Side window	Winds-creen	Interior pictures of the train	Overall interior design	Seat back	Seat side gear
								

5.4. Shape fusion and restructuring

5.4.1. Fusion and reorganization shape grammar rules

After completing the deduction of Dunhuang cultural styling factors and the extraction of characteristic lines of rail trains, it is necessary to achieve the organic unity of the two through systematic fusion and recombination methods, ensuring that Dunhuang cultural genes can be naturally embedded into the exterior design of rail trains.

Based on the theory of shape grammar, a systematic innovative method for integrating cultural genes and engineering design is constructed. The entire fusion system consists of three levels of grammar rules: the engineering grammar rules of Lanzhou Metro Line 1 (A1), the Dunhuang cultural styling factor grammar rules (S1-S3), and the reorganized and innovative design grammar rules (R1-1, R1-2, R1-3...) [16]. Firstly, establish a mapping matrix for grammar rules, and arrange and combine the key grammar rule A1 of the subway structure with Dunhuang cultural styling factors (B2 factor corresponds to S1 rule, B8 factor corresponds to S2 rule, B14 factor corresponds to S3 rule). Through this method, fusion and recombination are carried out to create new forms of design that meet specific needs, resulting in diverse design schemes. New forms that meet the positioning are screened to guide subsequent innovative designs.

In the design of subway exterior styling, the styling factors B2, B8, B14 are integrated with the vehicle structure lights, windshields, and side windows. The reorganized shape elements are shown in Figure 4.

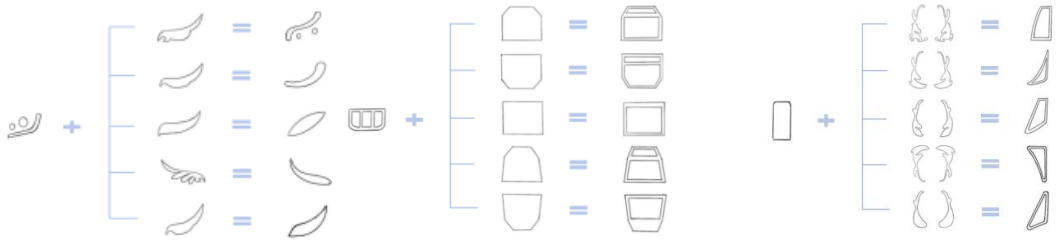


Figure 4. Integration and reconstruction of subway external structure and modeling elements

In the design of subway interior seats, the styling factors B8 and B14 are integrated with the seat back and armrest, and the reorganized shape elements are shown in Figure 5.

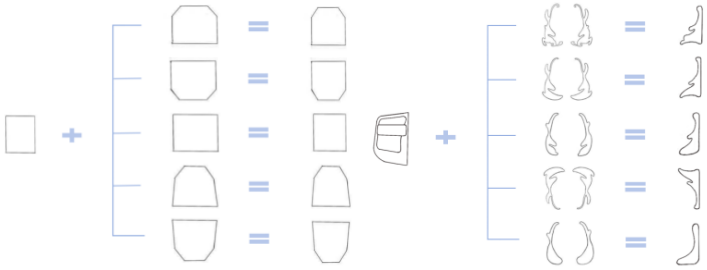


Figure 5.Integration and reconstruction of subway internal structure and modeling elements

5.4.2. Train structural form feature library

The styling factors B1, B8, B14 were fused and reorganized with the train structure styling. Based on the shape grammar rules of the fusion and reorganization, the styling factors were regularized and deduced, and a rail vehicle form feature library PA={PA1 headlights, PA2 side windows, PA3 windshields, PA4 seat side shields, PA5 seat backs} was constructed and numbered. The headlight form elements are I1- I 5, the side window form elements are II1-II 5, the windshield form elements are III1-III 5, the seat side shield form elements are IV1-IV 5, and the seat back form elements are V1-V5. The final deduction results are summarized in Figure 6. By transforming abstract Dunhuang cultural elements (B2, B8, B14) into quantifiable morphological feature elements (I-V series), a paradigm shift between traditional culture and modern design has been achieved.

Figure 6. Train structural form feature library

6. Design practice of rail trains

Using the train structural form feature library to carry out industrial design practice of trains, the exterior design selects car lights (I5), side windows(II4), and windshield(III5), and the interior selects several typical features such as seat armrests(IV1) and seat backrests(II3) for combination creation; In terms of painting, the exterior of the train mainly uses the color factor C2 with the highest weight value, while the interior mainly uses the color factor C1 with the second highest weight value. The final subway vehicle display images are shown in Figure 7 and Figure 8.

Figure 7. Exterior rendering of the train

Figure 8. Interior rendering of the train

7. Retrospect and prospect

Over the past 20 years, practice construction and related research on the Master Teacher Studio have made significant progress. Building upon this foundation, this study explores methods for applying Dunhuang cultural genes to railway train design. Through in-depth analysis and extraction, it proposes an innovative pathway that integrates culture with design, ultimately enhancing the cultural value of railway transportation. Research has shown that the unique elements of Dunhuang culture, such as color, texture, form, and symbolic meaning, can inject rich cultural connotations into rail transit design. By using Analytic Hierarchy Process (AHP) to rank the weight of Dunhuang cultural genes, a systematic cultural factor extraction model was established, providing a scientific basis for design practice. At the same time, the application of shape grammar successfully transformed the visual elements of Dunhuang culture into the design language of the appearance of rail trains, ensuring the organic integration of cultural and formal aesthetics in design. This study provides a new theoretical framework and practical path for the inheritance of Dunhuang culture and the design of rail transit vehicles, and also provides important references and inspirations for the application of regional cultural genes in other design fields in the future.

Acknowledgments

The authors really appreciate the experts, designers and users who offer great help. This study is expected to provide some references to design practices.

Funding: Humanities and Social Sciences Research Project of Liaoning Provincial Department of Education (LJKMR20220851)

Disclosure statement

The author declares no conflict of interest.

Author contributions

Yazhuo Zou conceived the idea of the study. Ma Wenhui wrote an article. YuanYan Yuan analyzed the data. Liu Xiang established a model. All authors have read and agreed to the published version of the manuscript.

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