Research on Train Exterior Design Oriented to Natural and Humanistic Environment-friendliness

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Abstract. Various types of rail transit trains have been integrated into the daily life of people. On the basis of meeting the technical indicators of safety, high efficiency and comfort, the exterior design of the trains should also have the natural and humanistic characteristics and theme of the environment in which it operates. This paper focuses on four aspects of the rail transit trains and their natural and humanistic environment: (1) the types, exterior characteristics and operating environment of the rail transit trains; (2) comparative study on the exterior design of the rail transit trains; (3) the identification and design application of natural and humanistic elements in the operating environment of rail transit trains; (4) the train exterior design program oriented towards natural and humanistic environment-friendliness.

1. The background

Rail transit refers to a kind of vehicle or transportation system that the operating vehicles need to run on a specific track. After hundreds of years of development, according to the differences in service requirements and scope, the rail transit has gradually developed from the original railway traffic system to three types of national railway system, inter-city rail transit and urban rail transit. From the perspective of the development of the rail transit trains, the exterior design of the trains is the concentrated embodiment of machinery manufacturing, engineering technology, social culture and the aesthetics of the times [1]. The environment-friendliness of train exterior design means that the train exterior design should show the characteristics and themes of the natural and humanistic environment in which it operates as well as good identifiable degree and formal aesthetic sense, accord with the public aesthetic and recognition of cultural identity, and have the function of spreading cultural image on the basis of meeting the technical indicators of safety, high efficiency and comfort and so on. Combined with the elements of natural and humanistic environment in which the train operates, the train exterior design is carried out according to local conditions. It is the basic goal of environment-friendliness train exterior design to highlight the characteristic theme.

2. The type, appearance characteristic and operating environment of rail transit trains

The differences in the appearance of different types of rail transit trains are mainly determined by the factors such as running speed, carrying capacity and track form and so on. Due to the influence of air resistance on the running of the train, the shape characteristics of the locomotive is also affected by the speed of the train, especially the medium-speed train and high-speed train. The aerodynamic resistance increases squarely with the increase of the train speed. Therefore, the running speed of the train has
the greatest influence on the appearance characteristics. The main modeling features of the train can be divided into two parts: the locomotive and the body. The locomotive refers to the first carriage of the train (length =L), including the front end of the locomotive (length =L0) and part of the body (length =L1). Basically, all types of trains have provisions on the length (L) of the locomotive. And the length L0 of the front end of the locomotive usually has a certain range of values according to different types of trains. For example, the value for the trains on the high-speed railway is generally more than 6 meters, and the value for subway is less than 3 meters, and the value for tramcar is not more than 1.95 meters. Seen from the side view, the important contour reference points of the trains are vertex a, nose cone vertex b, diversion point c, bottom lowest point d[2], and the waist vertex e is the contour reference point of the front view. From the perspective of visual observation, the three-dimensional characteristics are more obvious in the locomotive part and the two-dimensional characteristics in the body part. The body design style is often the continuation of the locomotive design style.

Figure 1. Relationship between train speed and air resistance

High-speed trains (excluding maglev trains) are commonly used for wide-range and long-distance transportation with a speed of more than 250 kilometers per hour, mainly including high-speed trains and inter-city trains. In order to reduce the air resistance, the front end of the locomotive the high-speed train is usually designed as a relatively flat streamlined structure, so the shape of the high-speed train must meet the aerodynamic conditions. The high-speed trains generally run for a long distance by way of different regions. The appearance design is less affected by the regional environmental characteristics, and more attention will be paid to its symbolic meaning in the design, such as whether it can represent the generalized humanistic spirit and connotation. Due to a certain region of the operation scope of the intercity trains, the operation scope is not as wide as the high-speed trains. Therefore, it can show certain style and features of regional natural and humanistic environment in the aspect of appearance design.

Urban rail trains usually include subway trains, light rail trains, monorail trains, tramcar, etc., [3] which usually run at a speed less than 80 kilometers per hour. Due to the low speed, the locomotive is less affected by wind resistance. At the same time, in order to increase the transport capacity of the locomotive, the length of the front end of the locomotive of urban rail train is shorter. As it runs within the city, the urban rail train is an excellent carrier to highlight the characteristics of the city and publicize the spirit of the city, which is of great significance in displaying the natural and humanistic environment of the city. In the exterior design of urban rail trains, the sources of modeling materials are rich and diverse. Compared with other types of trains, it has certain advantages in highlighting the characteristics of natural and humanistic environment as well as creating the train appearance with distinctive themes.

3. Comparative study on the exterior design of rail transit train

Through the research, it is found that different types of trains differ greatly in the modeling design, and the same types of trains are relatively similar in terms of the design of the main form. The reason is that the train is gradually maturing in technical requirements, function settings, manufacturing costs and other objective conditions after a long period of development and optimization. Under such circumstances, only by fully studying the types of trains and its natural and humanistic environment, and analyzing and innovating the modeling objects that make up the modeling of the train, can an
environment-friendly modeling design scheme for the train with natural and humanistic characteristics and themes be formed. At the same time, the coating design of the train body is also an important aspect of the exterior design. The design of different colors and patterns will bring significant differences to the appearance of the same type of train.

3.1. Research on the basic form of train modeling design

The two most basic characteristic lines of train modelling are respectively the front face silhouette and side-looking silhouette, and the silhouette of front face of the same type of trains is relatively close. After superposition of the front face silhouette of several typical trains of the same type, it can be found that the front face silhouette of the urban rail train (subway, tramcar) is more upright and foursquare, and the front face silhouette of the high-speed trains and inter-city trains have greater differences and richer than that of city the urban rail train. The side-looking silhouette of the train can best highlight the shape characteristics of different types of trains. Usually f1, f2 and f3 are tramcars, f2 and f3 are subway, light rail and monorail train, f4 is medium-speed and high-speed train, and f5 is high-speed train.

![Figure 3. Comparison of the front face silhouettes of different types of trains](image)

![Figure 4. Comparison of side-looking silhouettes of different types of trains](image)

3.2. Analysis of the object of train modeling design

The high-speed trains and subway trains with typical appearance characteristics are studied as the representative objects of medium-speed and high-speed trains and urban rail trains respectively. Through comparison, it can be found that, regardless of the types, the objects of train modeling design basically include roof, front window, column (both sides of the front window), headlamp sets, cab door and door and so on. The medium-speed train and high-speed train also include nose cone (cowling), diversion trench and so on. The medium-speed train and high-speed train are greatly influenced by aerodynamics. The front end of the locomotive is longer and the modeling is largely restricted by the technical requirements. But the front end of the locomotive of urban rail train is shorter and the spatial sense of modeling is not prominent. Therefore, the modeling difference expressed by the side view of the same type of train is usually not obvious. On the contrary, the frontal view of the front face of the train shows that the “expression” expressed in the frontal view of the front face of different types of trains differs from one another due to the difference in the form and position of the modeling objects although the objects of modeling design of the same type of train are the same, which has a distinct emotional representation.
Figure 6. The objects of body modeling of high-speed trains and subway trains

Figure 5. Comparison of front view and side view of high-speed trains and subway trains

Figure 7. Comparison of headlight design of subway trains

From the frontal view of the front face, the modeling of the roof of the train is mostly arc-shaped, and the rectilinear modeling design is suitable for the train with upright and foursquare overall and detailed designs. There is a significant difference in the percentage of the area of the front window of the medium-speed train and high-speed train and urban rail trains in the area of the front view. For the medium-speed train and high-speed train, it does not exceed 25%, and that of the urban rail train is generally between 35% and 50%. The front window of the medium-speed train and high-speed train is usually designed as a whole piece of glass. Some of them add an observation window on both sides. According to the different structures of the front face of the urban rail train, the front window of the urban rail train has the design of the whole piece of glass, or the design of two pieces of glass, or three pieces of glass. The front end of the locomotive of medium-speed train and high-speed train is longer, and the gradient of the windows is large, resulting in greater bending degree of the column. And the form of column is also dominated by turning form and transition form, while the column of the urban rail train is generally flat with a small bending degree. The headlamp sets are the finishing point of the front face of the train. From the point of view of the shape, the headlamp is mainly round and rectangular; and the size of the lamp should be determined as a whole according to the requirement of illumination brightness and the proportion relation with the front face. There are three types of arrangement of the lamp sets: horizontal, vertical and oblique. Most of the headlamp sets designed in the early stage are mainly horizontally and vertically arranged. At present, the oblique arrangement of headlamps has become the mainstream. This kind of design is full of motion and change, which can make the front face look more energetic. From the perspective of position, the headlamps of high-speed trains are above 1/2 of the height of the front face, while those of urban rail trains are below the front window, which generally does not exceed 1/2 of the height of the front face. Generally speaking, the upper position of the headlamp sets seems to be more sharp and powerful than the lower position. The change of the distance between the left and right light sets of the locomotive also has a great influence on the visual perception of the front face of the train, which can make people feel the emotional feeling brought by the change of the “expression” in the front of the train. Cab doors and train doors are usually rectangular, and the trafficability characteristic, structural reliability and other factors are taken into considerations. As it is located in the front of the locomotive, the upper edge of the cab door sometimes changes with the curvature of the side profile of the front end of the
locomotive. The side windows of the train are mostly rectangular with little difference in modeling, which can be regarded as the innovation point of appearance characteristics.

3.3. Analysis of train coating method
The coating design of the train is mainly divided into two types: color design and pattern design. The color design includes the whole monochrome coating and multi-color coating. The multi-color coating usually uses one color as the dominant color and other colors as the auxiliary colors, which helps to unify the colors of the train body within a range of visual colors. The use of the color belt can enhance the visual effect of the train, highlight the sense of speed and rhythm of the train. And the pattern design is usually adornment-based, but also used as a corporate advertising in some circumstances. Such as Japan’s railway tourism has a cooperation with the Wildlife Adventure World in Wakayama and launches the special coating version of the Kuroshio train. With five popular giant pandas in the garden as the theme, it creates a surprise panda train, the appearance has a strong visual attraction. In the coating design of trains, attention should be paid to the types of trains. Generally, for the design of the medium-speed trains and high-speed trains, silver gray and white are used as the main color of the train, with some auxiliary colors with higher saturation. The color design of the urban rail train should focus on the color setting of the line and the characteristics of the natural and humanistic environment.

4. Identification and design application of natural and humanistic elements in the operating environment of rail transit trains
According to the research, the natural and humanistic elements of the operating environment where the rail transit trains operate mainly include natural ecology, cultural tradition, historical inheritance, architectural environment, industrial economy and characteristic themes and so on. Different types of trains have different degrees of relevance and closeness with the various elements in the natural and humanistic environment. Before the design work is carried out, the natural and humanistic elements should be studied and refined in a targeted way to seek appropriate points of entry and determine the source of design elements based on the design theme.

4.1. Natural ecology
Natural ecology refers to a region’s climatic conditions, geomorphic feature, species and distribution of animals and plants and so on. In the design of the train appearance, the harmony between the appearance of the train and the natural ecological environment should be considered. For example, the use of natural ecological elements as the source of design intention can often highlight the natural ecological attributes of the train appearance and obtain a wide range of affective identification. As a peninsula country, South Korea is surrounded by the sea on three sides. In the design for the new generation of “Sea Fog” high-speed train (HEMU-430X), the concept of the sea has been incorporated into its design to express strong, reliable and modern visual effects and emotional intention. It uses the image of shark for a bionic design, which implies the “Sea Fog” high-speed train is like a big land shark constantly heading towards higher speed goals.

4.2. Cultural tradition
Cultural traditions include all kinds of material, institutional and spiritual cultural entities and cultural consciousness that have existed in the past dynasties, such as traditional colors, national costumes, life
customs, concept of values, poetry, calligraphy and painting and so on. In the product design, the adoption of modern design methods with reasonable integration of the elements of traditional culture can often help the users to have a sense of cultural identity, improve the acceptance of the products. For example, in the traditional Chinese concept, the dragon and phoenix are the symbol of good luck. Since ancient times, there are also many allusions and legends about “prosperity brought by the dragon and the phoenix”. China’s “Fuxing” high-speed train (models for CR400AF and CR400BF) respectively adopts the images of dragon and phoenix as the modeling elements and naturally incorporates them into the exterior design of the train. The modeling of CR400AF evolved from “dragon head”, the color belt surround the locomotive came from “dragon beard”, and the silver-gray body presents a strong sense of technology and industrial quality[4]. The modeling of CR400BF evolved from “phoenix head”. From the side view, the front end modeling of the locomotive came from the side face of the peacock, especially the shape of the eyes, and the shape of the nose cone came from the shape of bird’s beak. The overall image is as natural as though it were living! The combination of the sense of science and technology and the intention of modeling is like nature itself.

Figure 10. The evolutionary process of CR400AF modeling
Figure 11. The evolutionary process of CR400BF modeling

4.3. Historical inheritance
Historical inheritance refers that the appearance characteristics of products formed in the early stage was gradually extended to the new generation of products as the product gene after years of development, forming the iconic features of the product appearance. Taking the Berlin subway as an example, after more than 100 years of development, the subway trains have already formed a unique style with very remarkable German characteristics. The Berlin subway train had always maintained a rational, concise and square modeling. In the early days, the front face of the train was almost a rectangular plane without any sense of hierarchy, and the design of the headlamps was also simpler. Only two round headlamps were located on both sides of the front face, and the models in the later time mostly used square headlamps. The subsequent models have made some adjustments to the front face of the train, making it more angular and adding some sense of depth, but it is still more upright and foursquare in general. In the coating design, the Berlin subway always uses yellow as the main color, and the window frames and roofs are sometimes matched with black, which is also one of the main characteristics of the Berlin subway trains.

Figure 12. Development of exterior design of Berlin subway trains

4.4. Architectural environment
The architectural environment will often affect the overall environment of the region. Therefore, the appearance of trains operating here will often adopt a relatively “harmonious” design method to correspond with the architectural style, so as to avoid the fierce conflict between the design style and the architectural environment. If the regional architecture has a heavy sense of history, then the modeling of the train and coating design are relatively conservative, like the tramcar in Goteborg of
Sweden, whose modeling and coating design are integrated with the surrounding building environment. If the operation area for the train is a modern business district or a new development area with modern buildings standing in great numbers, then the modeling and coating design of the train should reflect the sense of the times and the sense of science and technology.

4.5. Industrial economy

Industrial economy is one of the important economic characteristics of a region, which is closely related to the local industrial structure. Different cities have different industrial positioning. For example, New York, London and Hong Kong are the three major financial centers in the world, with financial and service industries as the main industries. Pittsburgh, Chicago, Houston and San Francisco are important industrial cities in the United States, with industrial manufacturing as the main industry. In the 15th century, the French city of Lyon had become one of the largest producing areas of silk fabrics in the world, and it was known as the “silk capital”. The tramcars running through the downtown area of Lyon have industrial characteristics in its appearance design, and its modeling comes from the image of silkworm and white is chosen as the main color of the train. As a result of the use of bionic design techniques, the integral shape appears lovely vivid; thus it well highlights the industrial characteristics and forms a unique landscape.

4.6. Characteristic themes

The characteristic theme refers to the design of trains into special patterns for a specific theme, which is used to strengthen the concept and connotation of the theme. In terms of train appearance, it is to carry on customized design on the appearance or coating effect of the train to make it meet the requirements of the theme. The Disney dedicated line trains in Hong Kong are more representative. In the front end of the train, the image of Donald Duck is used as the creative source of the modeling, and the image of Mickey Mouse is used for reference in the design of the shape of the window. With bright and shining coating design, it highlights a relaxed and happy theme. Generally, the train is subject to relatively large constraints in terms of modeling design, and it is also a common design method to highlight the distinctive themes through coating design.

5. The train exterior design program oriented towards natural and humanistic environment-friendliness

The work of the train exterior design oriented to natural and humanistic environment-friendliness includes the following design steps:

1. Define train type and design theme. The type of train is determined by the traffic demand, while the design theme needs to be selected according to the natural and humanistic environment where the train operates. As discussed in the third part of the article, there are many elements of the natural and humanistic environment where the train operates, and the design themes can be developed from each element. Therefore, the selection of key elements should follow the following rules: (1) distinctive and representative characteristics; (2) it has the plasticity of form; (3) the ability to display spirituality; (4) accord with the general aesthetic requirements.

2. Determine the main modeling elements. The modeling elements are mainly derived from the natural and humanistic elements that have been determined to be adopted. Through investigation, evaluation and other methods, the modeling elements suitable to be transformed into creative sources.
are selected from numerous formal symbols, and they will be ranked according to their close degree to the design theme and their aesthetic value. Generally, the best modeling element is chosen as the basis of modeling design, and other related elements can be coupled into the design scheme according to the design needs.

3. The modeling design is carried out around the design theme and the main modeling elements. The two-dimensional design scheme is formed by taking the front view and the side view of the train as the main part. In the modeling design, the basic requirements of train modeling aesthetics should be followed firstly. For example, the medium-speed train and high-speed train should reflect the sense of stability and speed, and the subway, tramcar and other urban rail trains should reflect the reliability and agreeableness. Secondly, modeling elements should be reasonably used to form an environmental-friendly design scheme by means of bionics, metonymy, abstraction, combination and other ways. Thirdly, the train modeling design needs to meet the general rules of modeling aesthetics, such as proportion and scale, change and unity, equilibrium and stability and so on.

4. Design and evaluation of three-dimensional modeling scheme. Based on the selected two-dimensional design scheme of train modeling, the appearance modeling is carried out with the engineering software to form a three-dimensional digital model and render the body material, color and pattern. The evaluation of the train modeling scheme is mainly the aerodynamic simulation evaluation of the three-dimensional digital model. After the scheme is passed, the methods such as wide-spectrum survey and eye movement test can be used to comprehensively evaluate the friendliness of the natural and humanistic environment of the three-dimensional digital model of the train by combining the elements of natural and humanistic environment and modeling elements.

6. Conclusion
With the construction and development of various kinds of rail transit systems, the exterior design of the train should not only consider the shaping of the form of train itself, but also consider the human-train-environment system as a whole. It is one of the ways in which the exterior design of trains can be widely recognized by the society to confirm the types and morphological characteristics of trains, reasonably incorporate natural and humanistic elements in the design of the appearance, and form an environment-friendly train design scheme with natural and humanistic characteristics and themes. The research results will provide theoretical and methodological basis for the exterior design of the train with natural and humanistic environment friendliness, provide guarantee for the quality of the train exterior design, and promote the change of the train-exterior design from “functionality” to the direction of “rationality”, “ecology”, “artistry” and “characteristic theme”.

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References
[1] Xie Xuanhui. Research on the Evolution of Urban Rail Transit Vehicle Modeling Design [J].Design, 2018, 10: 121-123.
[2] Xiang Zerui,Zhi Jinyi,Li Ran,etc. Research Progress and Challenge in Industrial Design of Urban Rail Train in China. [J].Journal of the China Railway Society,2019.
[3] GB/T5655-1985.[S]
[4] How were those handsome high-speed locomotives designed? China’s high-speed railway was revealed[EB/OL]. [2018-07-23]. http://www.sohu.com/a/241029871_208485