Research on Digital CMF Perception of Train Virtual Science Popularization Exhibits Based on the SOR Model

Yunpeng Zhang, Ran Tao*, Jiaxin Sun

School of Art and Design, Dalian Jiaotong University, Dalian, Liaoning 116028, China

*1259174034@qq.com

Abstract. This study investigates the perceptual influence of digital Color-Material-Finishing (CMF) in virtual train science popularization exhibits based on the Stimulus-Organism-Response (SOR) model. Three representative digital CMF schemes with different color, material, and lighting characteristics were constructed as experimental stimuli to examine users' technological perception, immersion, and participation willingness. A total of 51 valid questionnaires were collected using the Semantic Differential (SD) scale and analyzed through reliability testing, one-way ANOVA, and correlation analysis.

The results show that the technology-futuristic and future-concept schemes significantly outperform the industrial-historical scheme in technological perception, immersion, and participation willingness. Among these dimensions, immersion demonstrates the strongest correlation with participation intention, indicating that immersive perception plays an important role in user engagement. The findings provide preliminary empirical support for the applicability of the SOR framework in digital CMF perception research.

Keywords: Digital CMF; Virtual Train Exhibit; User Perception.

1 Introduction

With the rapid development of digital technologies, virtual reality (VR), augmented reality (AR), and interactive media technologies have significantly transformed the approaches of science popularization and cultural communication. Compared with traditional physical exhibitions, virtual exhibits are no longer constrained by temporal or spatial limitations and are capable of providing immersive and interactive experiences. As a result, virtual exhibition environments have gradually become an important medium for digital science popularization and public cultural dissemination.Under the national strategy of building a strong transportation system, improving public transportation literacy and promoting transportation culture have become increasingly important. In this context, traditional train science popularization exhibitions are evolving toward digitization, virtualization, and intelligent interaction. Virtual train exhibits not only expand the accessibility of transportation knowledge dissemination, but also provide users with immersive cognitive experiences through digital visual environments.

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Nevertheless, existing studies mainly focus on interaction technology, interface usability, and virtual scene construction, while relatively limited attention has been paid to the perceptual influence of visual CMF design in virtual science popularization exhibits. Traditional CMF theory primarily emphasizes the coordinated application of color, material, and finishing in physical products. Recent studies have gradually extended CMF concepts into digital and virtual environments; however, systematic research on digital CMF perception in virtual exhibition scenarios remains insufficient.

2 Research Theories and Model Frameworks

2.1 SOR Theory Basis

The Stimulus-Organism-Response (SOR) model, proposed by Mehrabian and Russell (1974), explains how external environmental stimuli affect individuals' emotions and behaviors. It comprises three core elements and emphasizes that environmental cues influence behavioral choices indirectly through altering internal psychological states [1].Relevant studies have applied the SOR model to digital design and virtual exhibitions. Gao Jie took digital CMF attributes as stimulus variables, exploring their impact on users' experience-sharing behavior through motivational perception[2].Haodong Sun et al. built a "interface aesthetics-user perception-interactive behavior" framework based on the SOR model, confirming that digital visual stimuli influence interactive behavior through emotional and perceptual states[3].Naseri et al. proposed that packaging design stimuli influence consumers' purchase intention through cognitive and affective responses, further validating the applicability of the SOR-based packaging perception framework in consumer behavior research[4].Ronghui Wu et al. combined the SOR model with Experience Economy theory, showing that virtual exhibit visual aesthetics affect users' immersion and behavioral intention[5]. Matsumoto et al. noted that virtual exhibition spatial vision and circulation influence immersive experience[6]. Supported by existing literature and practical needs, this study adopts the SOR model as the basic theoretical framework for subsequent research on CMF in train virtual exhibits.

2.2 Research Model Diagram

The proposed research model is illustrated in Figure 1.

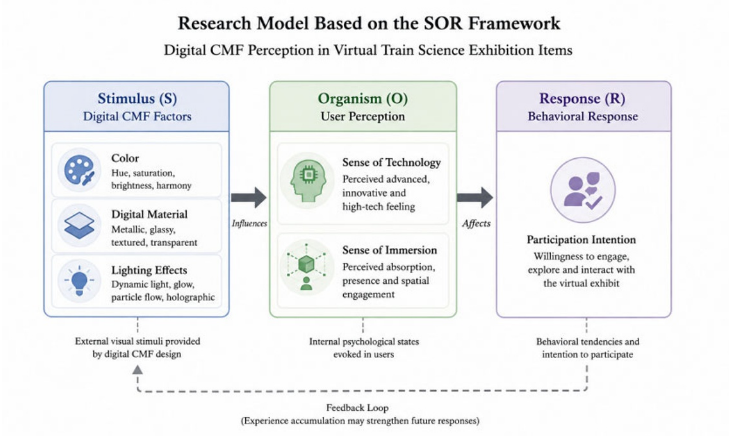

Fig. 1. Research Model Framework

3 Research Methods

3.1 Experimental Design

To investigate the perceptual influence of digital CMF on virtual train science popularization exhibits, this study adopted a comparative experimental approach. The research focused on three major visual dimensions of digital CMF: color configuration, digital material expression, and lighting effects. Participants evaluated different virtual exhibition schemes after viewing the experimental stimuli.The Semantic Differential (SD) scale was employed to measure users' perceptual responses in terms of technological perception, immersion, and participation willingness. Descriptive statistical analysis, reliability testing, one-way ANOVA, and correlation analysis were conducted using SPSS 27.0 to examine perceptual differences among the three experimental schemes and to verify the relationship between digital CMF perception and behavioral intention.

To reduce interference caused by non-CMF factors, all experimental schemes maintained the same spatial structure, exhibition content, and interface layout. Only the digital CMF elements, including color tone, material texture, and lighting atmosphere, were adjusted across different schemes.Unlike single-factor laboratory experiments, this study emphasizes the holistic perceptual characteristics of digital CMF in virtual exhibition environments. Therefore, the present study mainly focuses on overall perceptual tendencies instead of quantitatively isolating the independent contribution of each CMF factor.

3.2 Stimulus Material Design

To ensure obvious perceptual differences among experimental stimuli, this study constructed three representative digital CMF schemes based on different exhibition atmosphere orientations. All schemes kept the same spatial structure and exhibition content, with only digital color, material and finishing (CMF) elements adjusted, so as to reduce interference caused by other design variables.

Scheme A: Technology-Futuristic Style(See Table 1 and Figure 2).

Table 1. Keywords of Future Technology Style.

Digital CMF Element	Design Description
Color	Cold blue and white tones with high brightness and low warmth
Digital Material	Metallic materials, glass interfaces, reflective surfaces
Lighting Effects	Dynamic light flow, particle effects, luminous edge lighting

Fig. 2. Technology Future Style Test Image.

Scheme B: Industrial-Historical Style(See Table 2 and Figure 3).

Table 2. Keywords of Industrial Historical Styles.

Digital CMF Element	Design Description
Color	Warm yellow, copper, and dark brown tones
Digital Material	Rusted metal textures, wood materials, industrial rivet structures
Lighting Effects	Static warm lighting and low-brightness ambient light

Fig. 3. Industrial History Style Test Chart.

Scheme C: Future Concept Style(See Table 3 and Figure 4).

Table 3. Future Concept Style Keywords.

Digital CMF Element	Design Description
Color	Purple-blue gradients and deep-space black tones
Digital Material	Translucent digital materials and fluid-like virtual textures
Lighting Effects	Holographic lighting, floating light particles, spatial energy flow

Fig. 4. Future Concept Style Test Image.

3.3 Questionnaire Design and Collection

The Semantic Differential (SD) scale was adopted to evaluate users' perceptual responses under different digital CMF conditions. The questionnaire mainly included three perceptual dimensions: technological perception, immersion, and participation willingness. Detailed measurement items are presented in Table 4. The questionnaire was distributed through the Wenjuanxing online survey platform. Participants were first instructed to observe the three virtual exhibition schemes and then complete the perceptual evaluation questionnaire. A total of 55 questionnaires were collected, among which 51 valid responses were retained after data screening.The SD scale is widely used in perceptual evaluation research because it effectively captures users' subjective responses to visual stimuli. However, subjective evaluation may still involve cognitive bias when assessing immersion and emotional engagement.

Table 4. Questionnaire Test Items.

Dimension	Measurement Item	Scale Type
Sense of Technology	Not technological ←→ Highly technological	5-point SD scale
	Traditional ←→ Modern	5-point SD scale
	Low-tech ←→ High-tech	5-point SD scale
Sense of Immersion	No immersion ←→ Strong immersion	5-point SD scale
	Unattractive ←→ Highly attractive	5-point SD scale
	Weak spatial feeling ←→ Strong spatial feeling	5-point SD scale
Participation Intention	Unwilling to participate ←→ Very willing to participate	5-point SD scale
	Unwilling to explore ←→ Very willing to explore	5-point SD scale
	Unwilling to revisit ←→ Very willing to revisit	5-point SD scale

4 Research Data Analysis

SPSS 27.0 was used for questionnaire reliability and validity analysis. All three variables had α above 0.7 and the overall α over 0.9, confirming satisfactory reliability. The overall KMO value was 0.842, and Bartlett's sphericity test reached $p < 0.001$, indicating strong inter-variable correlation and good construct validity. The data were suitable for factor analysis and path verification.Mean and standard deviation of the three digital CMF schemes were calculated for each dimension. Scheme A had the highest technological perception score of 4.58, proving that cool tones, dynamic light flow and metallic materials effectively convey a sense of technology. Scheme C ranked first in immersion at 4.71, showing that translucent materials, holographic lighting and dark tones better create immersive virtual experience. Scheme B scored lower in all dimensions, matching its traditional and nostalgic positioning; industrial materials were more inclined to emotional narration than immediate digital sensory impact.

One-way ANOVA was performed, with $p < 0.05$ taken as the significance level. Extremely significant differences existed among the three schemes in technological perception ($F=18.42$, $p<0.001$), immersion ($F=15.67$, $p<0.001$) and participation willingness ($F=21.05$, $p<0.001$). Schemes A and C outperformed Scheme B significantly in technological perception and immersion. For participation willingness, no significant difference was found between A and C ($p>0.05$), while both were significantly higher than B. It reveals that both technology-oriented and conceptual CMF styles can better attract user participation in virtual train exhibits.Pearson correlation analysis was adopted to examine the relationship between Organism (O) and Response (R) in the SOR model. Technological perception was positively correlated with participation willingness ($r=0.724$), implying that a high-tech image shaped by digital CMF enhances users' exploration intention. Immersion had the strongest correlation with participation willingness ($r=0.781$), demonstrating that spatial immersion is the core driver of users' sustained engagement and repeated visiting intention.The above results further provide preliminary support for the applicability of the SOR framework in digital CMF perception research. Significant differences among the three CMF schemes in technological perception and immersion indicate that digital CMF stimuli can effectively influence users' internal perceptual states. In addition, the positive correlations between technological perception, immersion, and participation willingness further support the "Organism–Response" relationship proposed by the SOR model.

5 Conclusion

This study explored the perceptual effects of digital CMF in virtual train science popularization exhibits based on the Stimulus-Organism-Response (SOR) framework. Through comparative experiments involving three representative digital CMF schemes, the research examined users' technological perception, immersion, and participation willingness in virtual exhibition environments.The results indicate that different digital CMF schemes produce significantly different perceptual responses. The technology-futuristic and future-concept schemes achieved higher scores in technological perception, immersion, and participation willingness, whereas the industrial-historical scheme showed relatively lower technological perception but demonstrated stronger characteristics in historical atmosphere and cultural memory expression.The findings further suggest that cool color tones, metallic digital materials, translucent textures, and dynamic lighting effects can effectively enhance users' technological cognition and immersive experience in virtual environments. In particular, immersion showed the strongest positive correlation with participation willingness, indicating that immersive spatial perception is an important factor influencing users' exploration intention and sustained engagement behavior.From the perspective of the SOR framework, the study preliminarily verifies the influence path from digital CMF stimuli to users' internal perceptual states and further to behavioral intention. Significant differences among experimental schemes support the"Stimulus–Organism"relationship, while the positive correlations between perception dimensions and participation willingness support the"Organism–Response"mechanism proposed by the SOR theory.

Nevertheless, several limitations remain in the present study. First, the research adopted representative CMF combination schemes rather than isolated single-variable experiments. Therefore, the independent contribution of individual CMF elements could not be quantitatively distinguished. Second, the study mainly relied on Semantic Differential scales for perceptual evaluation and did not incorporate objective behavioral or physiological indicators. Finally, although correlation analysis provided preliminary support for the SOR mechanism, regression analysis or structural equation modeling was not further conducted due to the relatively limited sample size.Future research may combine factorial experimental methods, behavioral tracking technologies, and path analysis models to further investigate the causal relationship and interaction mechanisms among digital CMF stimuli, perceptual cognition, and behavioral intention in virtual exhibition environments.

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