Collaborative Design of Digital UI Design in Pavilion Orientation: An AI-driven Information Visualization and Moving Line Planning Method

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Abstract. In view of the lack of coordination between the space guidance system and the digital interface information visualization in the design of the exhibition hall, the cognitive load of the visitors will increase and the efficiency of the moving line will decrease. Therefore, this study proposes an AI-driven collaborative design method. Firstly, the spatial-information dual features are extracted from the spatial layout of the exhibition hall and the content of the digital interface. And build a visitor behavior prediction model. Secondly, the mapping relationship between the spatial guidance node and the digital interface information level is established,and respectively utilize Deep Q-Network (DQN) and Conditional Variational Autoencoder (CVAE) to generate optimized circulation planning and interface layout solutions.The AI algorithm is used to generate an optimized moving line planning and interface layout scheme. Finally, the man-machine collaborative work process of 'AI generation + designer optimization' is formed.

Keywords: Exhibition Hall Space Orientation; Digital Interface; Information Visualization; Moving Line Planning; AI-Assisted Design

1 Introduction

With the rapid development of digital display technology, modern pavilions have changed from a single static display space to a composite information environment that integrates physical space and digital interface. The experience of visitors in the pavilion depends not only on the rationality of spatial layout and guidance system, but also on the information visualization quality of digital interface[1-2]. From the existing research, the space-oriented design of the exhibition hall mainly focuses on the line planning, identification system and spatial cognition[3-4]. Digital interface design focuses on information architecture, interaction and user experience [5-6]. The rapid development of artificial intelligence has brought new possibilities to the design field[7-8]. However, in the complex scenario of pavilion-oriented design, the AI-assisted method has not effectively solved the problem of coordination between space orientation and interface.The human-machine collaborative work process of 'AI

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generation + designer optimization' was developed. This method aims to improve the overall navigation efficiency of the exhibition hall and reduce the cognitive load of visitors.

2 Methods

2.1 Space-information Dual Feature Representation

The purpose of this study is to solve the core problem of how to collaboratively optimize digital UI design and pavilion orientation. As shown in Figure 1, this method follows the following processes: spatial layout collection, interface content analysis, spatial-information feature extraction, mapping rule construction, AI-assisted scheme generation, and designer optimization (Fig.1).

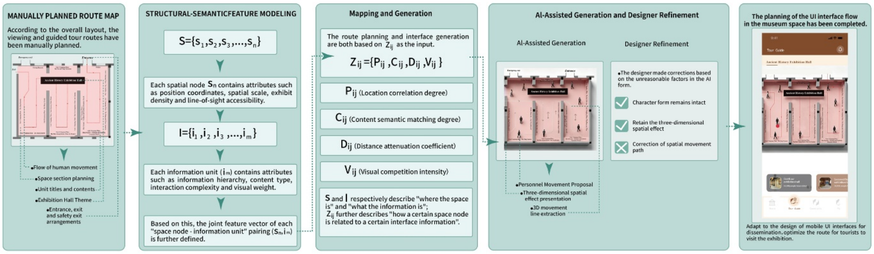

Fig. 1. Overall research framework

In this study, the exhibition space is represented by a set of spatial nodes:

$$S=\{s_1,s_2,s_3,\ldots,s_n\}$$

Each spatial node s_n contains attributes such as location coordinates, spatial scale, exhibit density, and line-of-sight accessibility. At the same time, the digital UI design content is represented by a set of information units:

$$I=\{i_1,i_2,i_3,\ldots,i_m\}$$

Each information unit i_m contains attributes such as information level, content type, interaction complexity and visual weight.

On this basis, the joint feature vector of each 'spatial node-information unit' pairing (s_n,i_m) is further defined:

$$Z_{ij}=\{P_{ij},C_{ij},D_{ij},V_{ij}\}$$

Among them:

P_{ij} (Location correlation degree):the matching degree of spatial node s_n and information unit i_m in physical location; C_{ij} (Content semantic matching degree): the semantic consistency between the content of the exhibits and the interface information; D_{ij} (Distance attenuation coefficient): the spatial distance influence of the visitor from the current position to the information touch point; V_{ij} (Visual competition intensity): the degree of visual interference between multiple interfaces or guiding elements at the spatial node.There is a clear progressive relationship between the above three levels of representation: S and I describe 'where is the space' and 'what is the information' respectively; Z_{ij} further describes 'how a spatial node is related to a certain interface information';subsequent moving line planning and interface generation Z_{ij} are used as basic inputs.

2.2 Visitor Behavior Prediction Model

The vector Zij provides a reasonable prediction of visitor behavior at different spatial nodes. The model comprehensively considers three factors.Spatial attraction: spatial attributes such as the importance of exhibits, spatial openness, and accessibility of sight have a natural guiding effect on visitors;Information trigger intensity: the visual saliency of the digital UI interface, the level of information, and the degree of attraction to visitors' attention;Spatial-information coupling degree: the comprehensive effect of position matching, semantic matching, distance attenuation and visual competition reflected in Z_{ij} .The model employs a three-layer feedforward neural network, taking the 4-dimensional features of Z_{ij} as input and outputting interaction probability and dwell time. Trained and validated on 2,847 instances of on-site behavioral data, the model achieves an AUC of 0.84 for interaction probability and an MAE of 5.7 seconds for dwell time.

2.3 Mapping Rules of Spatial Orientation and Interface Information

The mapping rules between spatial wayfinding nodes and the information hierarchy of digital UI design are shown in Table 1.

Table 1. Space-information mapping rule table

Type of space node	Interface information level	Recommended interaction mode	Visual performance strategy
Entrance / hall	Global navigation	Touch map / AR guidance	High contrast, large size
Exhibition entrance	Overview of the region	Information Kanban / scan code acquisition	Icon-led, hierarchical clear
Before the core exhibits	Deep content	Interactive screen / details page	Immersive, scalable
Passage / transition zone	Lightweight tips	Wall projection / ground guidance	Simple, non-interference
Rest area	Auxiliary information	Mobile push	Personalized, optional reading

The mapping rules were manually established by three exhibition hall design experts, based on principles of cognitive psychology and industry standards. The information hierarchy is divided into four levels by depth: global navigation, area overview, in-depth content, and lightweight prompts. The rules are used fixedly without introducing data-driven learning.

2.4 AI-assisted Dynamic Line Planning and Interface Generation

This study adopts a collaborative mechanism of 'AI-driven divergence + designer-led integration.' Circulation planning employs Deep Q-Network (DQN), with the state defined as the current node and visit history, and the reward combining exhibit coverage and movement cost. Interface layout adopts a Conditional Variational Autoencoder (CVAE), generating candidate solutions conditioned on node type and information hierarchy. Both algorithms are implemented using PyTorch. Designers evaluate and optimize the generated results based on four criteria: spatial-information consistency, wayfinding efficiency, interface readability, and overall experiential coherence.

3 Experiment and Analysis

3.1 Sample Construction and Experimental Setup

In order to verify this method, the permanent exhibition area of Jiamusi Museum is selected as the experimental scene.Extract 24 information units from the digital interface content of the exhibition area. It is divided into four categories: global navigation, exhibition area overview, deep content, and lightweight prompts.

1. Group A (traditional design): completed independently by professional pavilion designers and UI designers. No AI assistance (Fig.2).

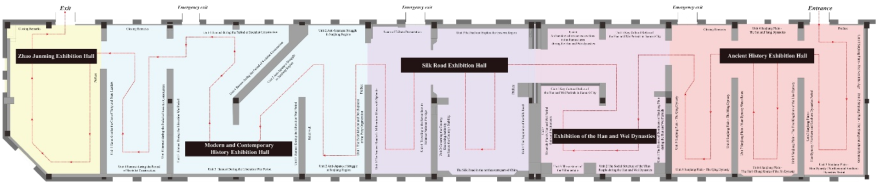

Fig. 2. Traditional design line diagram

2. Group B (pure AI generation): only based on spatial layout data to generate dynamic lines and interfaces. No manual optimization (Fig.3).

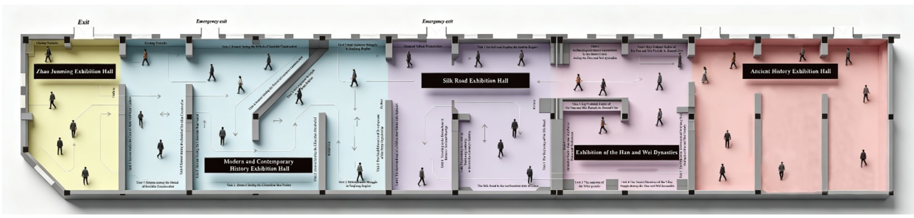

Fig. 3. Pure AI design line diagram

3.Group C (this method): a human-machine collaboration method combining space-information mapping rules, AI generation and designer optimization (Fig.4).

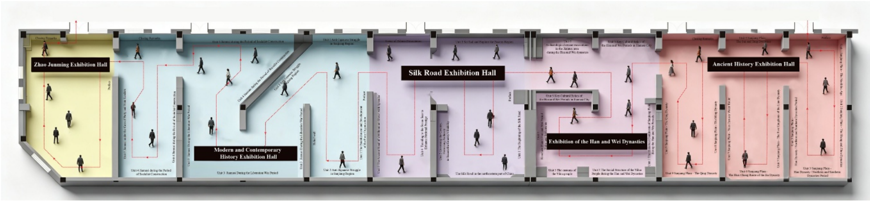

Fig. 4. AI-driven divergence + designer-led integration diagram

Sixty participants (aged 22-45, half male and half female) were recruited and randomly assigned to three groups (20 per group). The experiment was conducted in a 1:1 digital twin environment of the exhibition area, with each session lasting 25-30 minutes (including a 5-minute instruction period).Task order was randomized within each group.Subjective indicators:Guided clarity;UI interface ease of use;Overall satisfaction;Cognitive load (reverse scoring);Behavior indicators:Wayfinding time (seconds);Information acquisition accuracy (%);Number of invalid stays.

3.2 Results and Discussion

One-way analysis of variance was used to analyze the data (Table 2). The results showed that there were significant differences in all indicators between the groups ($p < 0.001$). Among them, group C had the best overall performance.

Table 2. User evaluation and statistical analysis results

Groups	Orientation Clearness	Interface Ease of use	The whole Satisfaction	Cognitive load	Way-finding time (s)	Accuracy (%)	Number of invalid stays
Group A: Traditional Design	5.42±0.68	5.38±0.72	5.31±0.65	4.95±0.71	187.3±22.4	78.6±8.3	5.8±1.6
Group B: Pure AI generation	4.85±0.81	4.72±0.79	4.63±0.74	5.68±0.82	224.6±28.7	69.4±9.1	7.4±2.1
Group C: This method	**6.21±0.54**	**6.08±0.51**	**6.15±0.48**	**3.82±0.63**	**142.5±18.6**	**88.2±7.4**	**3.6±1.2**
Comparison between groups (F value)	38.42	41.27	35.96	52.18	47.63	32.85	41.09

$*p<0.001$.

Results revealed three main findings: First, collaborative design significantly improved navigation efficiency, with Group C's wayfinding time reduced by 24%

compared to Group A and 37% compared to Group B. Second, human-AI collaboration outperformed pure AI generation, as Group B performed worst across all metrics, while Group C compensated for AI's semantic deviations through designer optimization. Third, cognitive load was significantly reduced, with Group C's score (3.82) outperforming Group A (4.95) and Group B (5.68).

4 Conclusion

This study proposes an AI-driven collaborative method for digital UI design and exhibition hall spatial wayfinding. By establishing mapping rules between spatial nodes and information hierarchy, and introducing the joint feature vector Z_{ij} as a unified representation linking space and interface, the method integrates spatial layout, circulation planning,and interface visualization within a human-AI collaborative framework of 'AI generation + designer optimization.'Experimental results show that this method significantly outperforms both traditional design and pure AI generation in terms of wayfinding clarity, navigation time, accuracy, and cognitive load. Comparison of the three sets of floor plans verifies that human-only design lacks efficiency, pure AI generation lacks semantics, while the AI + designer optimization approach achieves both spatial coherence and interactivity.This study provides an interpretable and reusable AI-assisted framework for the integrated design of digital UI and exhibition hall wayfinding. Future research will extend to multi-exhibition scenarios, introduce physiological metrics such as eye tracking, and improve evaluation methods under more complex visiting conditions.

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