Design and Implementation of Interactive Public Spaces Based on Digital Twin Technology

Shunhai Li *

Nanchang Institute of Technology, Nanchang, Jiangxi, China

*** Corresponding author Email:** lishunhaisean@163.com

Abstract: Interactive public spaces are gaining increasing attention in modern interior design, with their core focus lying in achieving a unified blend of functionality and experiential value. This paper establishes a design framework supported by digital twin technology, comprising data collection, virtual-physical integration, and dynamic feedback. Through BIM modeling and multi-source data integration, it achieves high-precision virtual mapping of interior spaces. Utilizing AR/VR and interactive installations, it enhances user immersion and engagement. Combined with real-time monitoring and feedback mechanisms, it optimizes spatial operational states. Analysis indicates this approach significantly improves spatial flexibility and interactivity, offering new perspectives and technical pathways for public space design.

Keywords: Digital Twin; Interior Design; Interactive Space; Virtual-Physical Integration.

1. Introduction

With the advancement of smart cities and intelligent buildings, the functions of indoor public spaces are shifting from single-use to multidimensional interaction, while design philosophies increasingly emphasize the integration of experience and efficiency. Traditional interior design faces limitations in dynamic adaptability and user engagement, whereas digital twin technology offers novel solutions. By constructing virtual-physical mapping models, real-time monitoring of spatial conditions, multidimensional presentation of interactive designs, and feedback-driven dynamic optimization become achievable. This study explores interactive public space design methodologies based on digital twins. From needs analysis and virtual-physical integration to system implementation, it proposes flexible and immersive interior design pathways to comprehensively enhance public spaces in functionality, experience, and intelligence levels [1].

2. Needs Analysis for Interactive Public Space Design

Interactive public spaces fulfill multiple functions in interior design—social interaction, exhibition, and experiential engagement. Their requirements analysis should unfold across three dimensions: user behavior, spatial functionality, and technological support. At the user level, diverse groups exhibit differentiated needs for leisure, learning, communication, and immersive experiences. Regarding spatial functionality, indoor public spaces require flexible layouts, comfortable and safe environments, and multi-scenario compatibility to accommodate dynamic shifts between peak usage and low-frequency occupancy. At the technical support level, real-time data collection, visual interaction, and feedback optimization through digital twins form the essential foundation for interactive experiences [2]. To intuitively illustrate the interrelationships among these elements, a multidimensional requirements matrix can be constructed. This matrix systematically displays the cross-relationships between user needs, spatial attributes, and technical conditions, as shown in Figure 1.

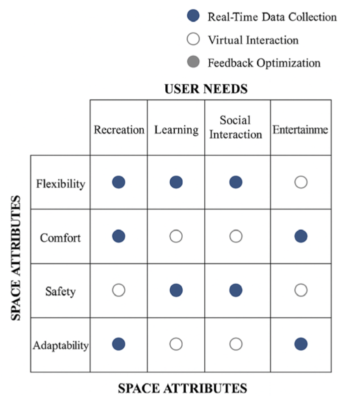

Figure 1. Multi-dimensional Requirements Matrix Diagram

3. Interactive Public Space Design Methodology Based on Digital Twins

3.1. Data Collection and Modeling

Data collection serves as the prerequisite for modeling in constructing digital twins for interactive public spaces. Sensors, cameras, and IoT devices are deployed to capture spatial geometric parameters, environmental information, and pedestrian behavior data [3]. During modeling, BIM technology is first employed to establish geometric models of indoor spaces, followed by multi-source heterogeneous data fusion to achieve dynamic scene reconstruction.

The data mapping relationship can be expressed as:

$$M = f\left(G, E, U\right) \tag{1}$$

Where M represents the digital twin model, G denotes geometric spatial data, E signifies environmental parameters, and U indicates user behavior information. Through the real-time update function $M\left(t\right)$, dynamic consistency between the model and physical space is achieved.

3.2. Interactive Design for Virtual-Physical Integration

In interactive public spaces, the fusion of virtual and real elements is crucial for achieving immersive experiences. Leveraging augmented reality (AR), virtual reality (VR), and projection technologies, the digital twin model establishes a bidirectional mapping with the actual indoor environment. This enables users to perceive and manipulate real-world spatial elements within a virtual interface. For instance, lighting scenes can be adjusted in real-time based on virtual simulations, while furniture layouts can be previewed and interacted with through virtual projections, enhancing the intuitiveness and engagement of design decisions [4]. Concurrently, the interactive system generates personalized spatial feedback based on user behavior data to optimize the spatial experience. To clearly illustrate the mapping relationship between virtual designs and physical spaces, a comparative diagram of virtual-physical integration and interior space design can be constructed, as shown in Figure 2.

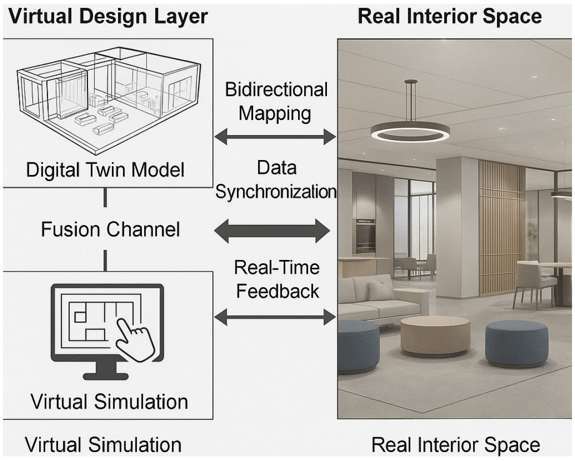

Figure 2. Comparison of Virtual-Physical Integration and Interior Space Design

3.3. Dynamic Optimization and User Feedback

In interactive public space design, dynamic optimization and user feedback are core elements ensuring long-term adaptability and interactive value. Through digital twin platforms, indoor sensors can collect real-time parameters such as crowd density, ambient lighting, temperature/humidity, and noise levels, mapping this data to the virtual space for instantaneous status monitoring [5]. When the system detects localized crowding or declining environmental comfort, it can automatically trigger adjustment mechanisms—such as intelligent lighting adjustments, air quality optimization, or path guidance—to enhance user experience [6]. Users can provide feedback via mobile terminals or interactive interfaces, enabling the system to iteratively learn and optimize based on this data, forming a closed-loop mechanism of "collection-analysis-adjustment-verification."

4. Interactive Public Space Design and Implementation

4.1. Interactive Design for Indoor Spaces

The core of interactive indoor space design lies in user-centered approaches that create environments supporting immersive experiences, social interaction, and seamless scenario transitions. Emphasis is placed on spatial layout openness and flexibility. Through movable partitions, modular furniture, and adjustable lighting systems, spaces can rapidly adapt between exhibition, leisure, seminar, and entertainment modes to meet diverse usage demands. Interactive installations serve as key design elements. Utilizing smart projection walls, immersive screens, touch-sensitive surfaces, and motion-capture devices, these installations enable users to engage through multimodal visual, auditory, and tactile interactions. Visitors can manipulate wall projections with gestures to instantly access information or artistic content, while embedded touchscreens in furniture surfaces facilitate information retrieval and social interaction [7]. For environmental ambiance, lighting and sound systems synchronize with digital twin models, dynamically adjusting based on crowd density and interaction levels to ensure comfort and engagement. The spatial design emphasizes "virtual-physical integration," where user actions on virtual interfaces instantly reflect in real-world lighting, layout, and interactive installations, enhancing immersion. To visually illustrate the overall design concept, an interior interactive design schematic can be created, as shown in Figure 3.

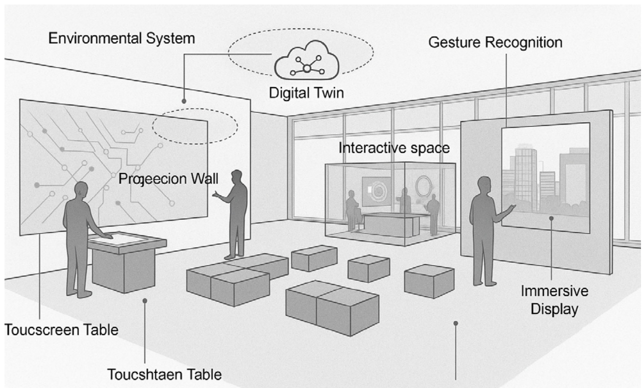

Figure 3. Design Drawing

4.2. Digital Twin System Implementation

The digital twin system relies on the coordinated operation of the data layer, model layer, and application layer. The data layer collects environmental parameters and user behavior data from indoor spaces via sensors, cameras, and IoT devices, enabling efficient real-time data transmission. The model layer constructs high-precision virtual space mapping based on BIM models and multi-source heterogeneous data fusion technology, ensuring consistency between virtual and physical environments through dynamic update algorithms. The application layer provides multi-terminal interaction interfaces—including projection screens, mobile apps, and AR/VR devices—enabling users to perceive and manipulate spatial environments in real time. The system incorporates feedback mechanisms that synchronously relay user actions and environmental changes, establishing a design-experience-optimization cycle.

5. Conclusion

This interactive public space design based on digital twin technology achieves deep integration between virtual and physical realms, establishing a dynamic system within indoor spaces that is perceptible, interactive, and optimizable. Research indicates that data collection and modeling provide an accurate foundation, while virtual-physical fusion interaction enhances user experience. Dynamic optimization and feedback mechanisms strengthen spatial adaptability and continuous improvement value. Through systematic design and implementation, public spaces demonstrate heightened flexibility and immersion. Future research may further expand cross-scenario applications, explore multimodal interaction methods, and evaluate long-term operational effectiveness, providing broader development pathways for digital twin-driven spatial design.

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