

Research on Strategies for Enhancing the Functionalities of Museum Exhibition Spaces through Digitalization

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Abstract: With the continuous development of the national cultural digitalization strategy and the construction of smart museums, the exhibition spaces of museums have transformed from simple places for displaying physical objects to comprehensive venues that include cultural narration, public services, and data management. This paper uses the methods of literature analysis and systematic induction to explain the meanings of digitalization and exhibition space functions, and analyzes the current phenomena such as content separation, spatial chaos, data isolation, identical experiences, and weak maintenance capabilities in the application of technologies. It proposes to center on cultural content, utilize digital narrative reorganization, digital twin improvement, multimodal interaction, classified services, data-driven maintenance, and secure collaborative management to enhance the exhibition, educational, aesthetic, guiding, communicative, and management functions of the spaces. The role of digitalization should prioritize the protection of cultural relics, be oriented towards the needs of the audience, and be based on appropriate technology, in order to achieve the common improvement of cultural value, spatial benefits, and public service quality.

1. Introduction

The exhibition venue of a museum is an important place for storing collections, promoting cultural dissemination, and meeting the needs of visitors. Traditionally, exhibitions were carried out through physical objects, text, and human explanations. However, there were some shortcomings in terms of information volume, interaction, and space adaptation. With the emergence of technologies such as big data, artificial intelligence, digital twins, and extended reality, the exhibition space can be transformed from a static display to an interactive experience and intelligent service. Currently, some museums have problems in their digitalization construction, such as emphasizing equipment over content and form over experience. Digital technology has not been well integrated with spatial landscapes, audience needs, management, and operation. Based on this, this paper analyzes the impact mechanism and practical difficulties of digitalization on the landscape functions of exhibition spaces, and proposes improvement measures to provide references for the improvement of museum exhibition spaces.

2. The Connotation and Mechanism of Digitalization Enabling the Landscape Functions of Exhibition Spaces

2.1 Core Concept Definition

Digitalization combines digitalization and intelligence. Digitalization is responsible for collecting, encoding, preserving, and disseminating information about collections, spaces, exhibitions, and audience services. Intelligence utilizes data analysis, knowledge organization, and algorithm models to perform environmental recognition, content recommendation, interactive responses, and auxiliary decision-making^[1]. The two are not independent technical stages but a continuous process of the sustained interaction between data resources, spatial facilities, and business mechanisms.

The landscape of a museum's exhibition space includes factors such as building interfaces, display cabinets and walls, lighting and colors, material textures, guidance systems, public art, recreational facilities, and digital media. Here, "landscape" does not merely refer to the visual arrangement but the overall spatial sensation formed by the audience's walking, staying, viewing, and contact. According to its functions, it can be divided into six types: first, the display function of showing collections and their cultural information; second, the narrative function of arranging exhibitions and their themes and meanings; third, the educational function of promoting learning, exploration, and knowledge establishment; fourth, the aesthetic function of creating atmosphere, emotions, and local identity; fifth, the public function of guiding, resting, communicating, and providing barrier-free services; and sixth, the management function of protecting cultural relics, organizing people flow, controlling energy consumption, and maintaining equipment maintenance.

2.2 Mechanism of Digitalization Enabling the Function of Exhibition Space Landscape

The improvement of the landscape functions of the exhibition space through digitalization is achieved through "data association - scene translation - interactive feedback - dynamic optimization". Standardized association of collection information, research results, spatial parameters, and service data can be transformed into calculable and callable knowledge assets. According to the theme of the exhibition, the relevant data is translated into light, sound, images, models, and spatial interfaces to supplement the historical background and relationship networks that physical objects cannot directly represent. Using sensing devices and interactive terminals, with authorization, obtain the behavioral feedback of the audience, and dynamically adjust information density, display rhythm, and service content. The operation data is used for route optimization, equipment maintenance, and exhibition evaluation to form a continuous improvement mechanism. The essence of digitalization enabling is not to increase the number of technologies, but to change the organization of space and the way of cultural dissemination, transforming the exhibition space from a one-sided information output to a two-way communication between people, objects, data, and the environment.

3. The Realistic Challenges in Enhancing the Landscape Function of Museum Exhibition Spaces

3.1 Disconnection between Technology Superposition and Content Expression

Some digital exhibits aim mainly at visual impact and have insufficient connection with the exhibition theme, the value of the collection, and academic research. Although projectors, screens, and interactive devices increase sensory stimulation, they may overshadow the cultural content and

make viewers remember the technological scenes instead of the cultural essence. When different suppliers build different exhibits, visual language inconsistency, content repetition, and different operation methods often occur, affecting the coherence of the spatial narrative.

3.2 Insufficient Coordination between Digital Media and Spatial Order

After digital devices are introduced into exhibition spaces, screen brightness, device size, sound diffusion, and viewer stay behavior will interfere with the original spatial layout. If the early design does not synchronously predict the sound and light environment and flow characteristics of people, problems such as excessively high light levels in certain areas, noise accumulation, crossing viewing flow lines, and local congestion are likely to occur. Inadequate coordination between rest points, sign guidance, and digital guided tours will also disrupt the viewing rhythm and reduce the comfort level of the viewing experience.

3.3 Dispersed Data Resources and Insufficient Spatial Application

Collections management, exhibition planning, ticket reservation, public education, and facility operation often use different systems, and data norms and interfaces are not unified, forming information islands. Many venues have accumulated a large amount of 3D models and high-definition image materials, but most of them are only used as archival materials and have not been transformed into exhibition resources that support spatial narrative and are open to the public. Audience research is often limited to basic statistics such as visit numbers and satisfaction levels, making it difficult to provide effective basis for exhibition theme iteration, targeted services, and precise spatial management.

3.4 Homogenization of Experience and Insufficient Publicity

Immersive scenes, digital restoration, and interactive games have become common exhibition means, but they also lead to the convergence of some exhibition forms and low recognition. Fixed information volume, interaction difficulty, and viewing routes are difficult to meet the differentiated needs of children, the elderly, professional researchers, and disabled viewers. Over-reliance on mobile device interaction will also form new digital barriers. Viewers unfamiliar with intelligent devices will have difficulty obtaining complete exhibition services.

3.5 Weaknesses in Continuous Operation and Security Governance

Digital exhibition hardware and software have a fast iteration speed, strong system interconnection, and high post-content maintenance costs. If the project construction stage only focuses on equipment procurement and neglects subsequent operation and maintenance, it is easy to encounter equipment frequent failures, outdated content, and incompatible system versions. Technologies such as facial recognition, location tracking, and viewer behavior analysis involve personal privacy, and 3D models and digital materials also have copyright and data security risks. Without corresponding institutional regulations, conflicts between technical application efficiency and public rights and interests are prone to occur.

4. Strategies for Enhancing the Functionalities of Exhibition Spaces through Digitalization

4.1 Adhering to Content as the Core, Reconstructing Digital Space Narratives

Firstly, based on the theme of the exhibition and the value of the collections, establish a three-level content structure of "core information - extended knowledge - interactive tasks". Core information is explained through the objects themselves, necessary graphics and spatial nodes. Extended content such as production techniques, historical environment and interpersonal relationships can be presented hierarchically through augmented reality, digital restoration and knowledge graphs. Interactive tasks serve observation, comparison and exploration, avoiding entertainment-oriented designs that deviate from educational goals^[2-3]. Secondly, integrate digital narratives into the entire space rather than treating them as a separate exhibit. The entrance hall can use digital means to establish the background of the era and problem awareness, the main exhibition area emphasizes physical evidence, the transitional space is responsible for the transformation of emotions and the supplementation of knowledge, and the end hall uses feedback devices to enable the audience to recall and express. The proportion, brightness and sound intensity of digital content should be in line with the status of the objects, forming a narrative rhythm that is both realistic and appropriate in tension and relaxation.

4.2 Utilizing Digital Twins to Optimize Space Organization and Environmental Landscape

When building or renovating exhibition spaces, a digital twin model integrating architectural structure, exhibition carriers, pipeline equipment, light environment and visitor flow lines can be established. In the design phase, use scene simulation to compare different exhibition wall layouts, viewing distances and stay locations, and identify sight obstructions, passenger flow conflicts and evacuation issues in advance. During the construction phase, use the model to arrange the safety of cultural relics, equipment installation and landscape interfaces, reducing repetitive construction. During the operation phase, while ensuring the protection of cultural relics, put temperature, humidity, equipment status under dynamic monitoring. Digital twins do not need to pursue high-precision replication of the exterior appearance; the accuracy and update frequency of the model should be determined based on actual work. For temporary exhibitions, simplified and modular models can be used to facilitate the rapid combination of exhibition walls, lighting and digital content.

4.3 Improving Multimodal Interaction to Enhance Educational and Public Service Functions

Exhibition interaction can develop from "touch screens" to voice, gestures, spatial positioning and physical operations, and select technologies based on content characteristics^[4]. For fragile cultural relics, high-precision images and three-dimensional models can be used to display details. For sites and historical environments, immersive images can be used to supplement the spatial background. For scientific collections, operable models and real-time reactions can be set up to enable the audience to understand the principles. The result of interaction should trigger new observations and thoughts rather than remaining at points of accumulation, special effects or simple entertainment. Additionally, different service methods should be established. For teenagers, set up inquiry-based tasks and cooperative learning scenarios; for elderly audiences, retain large-font text graphics, physical buttons and human services; for audiences with hearing and visual impairments, provide subtitles, sign language, voice descriptions and tactile assistance. Digital guided tours should provide basic, deep and professional content levels, allowing audiences to control the pace of the visit independently. Online resources can be used for pre-visit preview and post-visit

extension learning, but they cannot replace the physical perception and public interaction in the physical space.

4.4 Strengthening Data-driven Approaches to Formulate Precise Services and Dynamic Maintenance Mechanisms

Museums, under legal, legitimate and necessary conditions, should establish a collaborative mechanism for exhibition content, space facilities and audience services data. Through anonymous passenger flow analysis, identify high-frequency stay areas, inefficient exhibition areas and congestion nodes, providing basis for guidance adjustment, exhibit configuration and explanation arrangements. Combined with questionnaires, interviews and observation studies, analyze whether audiences truly understand the exhibition theme, avoiding evaluating the effectiveness of communication solely based on device click rates. Maintenance should include establishing equipment archives, fault prediction, content updates and spare parts management measures, and including digital exhibits in the regular inspection of the venue. For key exhibition items, set downgraded solutions such as offline playback, static graphics and text, or manual explanations to ensure that the basic exhibition functions are not interrupted in case of system failures. Connect business systems gradually through the data hub or unified interface, but do not blindly pursue "big and comprehensive". First, solve the frequently needed problems such as content sharing, equipment monitoring, and audience services.

4.5 Coordinate cultural relic protection, green low-carbon and spatial comfort

Digitalization construction must comply with the requirements of cultural relic safety and preventive protection. When adding new equipment, consider issues such as heat, vibration, ultraviolet rays, electromagnetic interference and maintenance. Prevent the micro-environment of the display case from being affected by lighting or immersive projection. For light-sensitive cultural relics, digital media can undertake part of the information explanation function, but should not pursue the display effect at the cost of extending the exposure time of the cultural relics. When arranging the environment, use intelligent control systems to adjust lighting and air conditioning during open hours, exhibition area usage, and changes in visitor flow, reducing unnecessary energy consumption. Try to select modular, easy-to-maintain and upgrade equipment to reduce resource waste caused by overall replacement. The color, materials and shapes of the digital interface should be adapted to the building environment, exhibition theme, and at the same time control sound leakage and visual interference to maintain the tranquility, comfort and aesthetic effect of the museum space.

4.6 Improve standards, ethics and collaborative governance system

Museums should formulate management norms covering data collection, content production, system interfaces, copyright authorization, personal information protection and operation maintenance. Data related to audience behavior should be processed as anonymized and aggregated as much as possible, and the collection purpose, retention period and access rights should be clearly defined. For historical images, explanatory texts and restoration content generated by artificial intelligence, an expert review and source annotation mechanism should be established to prevent algorithm-generated content from confusing historical facts and speculation. In terms of organization, it is necessary to promote the participation of curators, cultural relic protection personnel, space designers, education experts and technical personnel in project decision-making. The technology provider is responsible for implementing measures, but cannot replace the

museum's leadership over cultural content and public value. Through cross-disciplinary reviews, audience tests and third-party security evaluations, form a closed loop of construction, use, feedback and improvement.

5. Conclusion

Digitalization has provided new technical conditions for enhancing the landscape functions of museum exhibition spaces. However, its value does not lie in the addition of equipment and sensory stimulation, but in promoting the systematic reconfiguration of cultural content, spatial environment, audience needs, and operational governance. Museums should start from protecting cultural relics and providing public cultural services, focus on content narration, base it on data connections, and utilize digital twins, multimodal interaction, and intelligent maintenance to improve functions such as display, education, aesthetics, guidance, interaction, and management. Additionally, appropriate technologies, services tailored for different groups, safety ethics, and regular evaluations should be adopted to prevent formalistic construction. In the future, museum exhibition spaces will develop towards the direction of integration of virtual and real elements, dynamic adaptation, and cross-institutional collaboration. Digitalization construction should place greater emphasis on the authenticity of culture, the subject position of the audience, and the sustainability of technology, enabling museums to transform from places for knowledge display to open and shared cultural communication venues.

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