



Research on Digital Protection Design of Cultural Heritage and New Tourism Management Model in the Context of Integrating Reality and Illusion in the Display Environment

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SUMMARY: *This research is based on a virtual-real integration display environment, integrating the digital collection of cultural heritage, scene modeling, behavior data analysis, and tourism management evaluation. It has constructed a new data-driven model for cultural heritage protection and tourism management, and has carried out pilot applications in typical heritage sites. The empirical results show that the peak density of people in sensitive areas has decreased from 3.2 people/square meter to 2.1 people/square meter, the average stay time has decreased from 165 seconds to 98 seconds, the number of close-contact incidents has decreased from 5.3 times/day to 1.2 times/day, the reach rate of in-depth explanations has increased from 46.8% to 71.5%, the interaction participation rate has increased from 38.2% to 63.9%, and the comprehensive management score has increased from 68.9 to 84.8. These changes indicate that this model has obvious advantages in balancing the safety of cultural relics, the experience of tourists, and operational efficiency after the implementation of the plan, and provides a feasible practical path for the refined management and digital governance of scenic spots.*

Povzetek: Regarding the protection and management of cultural heritage in an environment where reality and virtuality are integrated, an integrated framework of "collection - modeling - rules - evaluation" is constructed. A three-layer system architecture and an object - space - behavior - rule scenario model are designed. Digital collection and risk assessment processes, protection rule engines, and tourism management evaluation models are proposed, providing technical support for the optimization of protection design and management models.

KEYWORDS: *Digital protection of cultural heritage; Virtual-real integration display environment; Visitor behavior data; New model of tourism management*

1 Introduction

In recent years, the digitization of cultural heritage has shifted from the early technical practice of "scanning - archiving - filing" to comprehensive issues such as "dynamic inheritance - cultural tourism integration - social governance". Regarding intangible cultural heritage, Wenyan Zhao and Yutong Liu [1] have from the perspective of cultural tourism integration analyzed the inheritance path of Jingdezhen ceramic intangible heritage under the "digital and intelligent empowerment", emphasizing the pivotal role of digital platforms in connecting manual skills, the industrial chain and tourism consumption; Xiaohui Yang and Gaofeng Mi [2] have utilized IIoT and Stable Diffusible LoRA multi-level tagging optimization technology to explore the intelligent generation and automated design of Mongolian embroidery patterns, enabling traditional patterns to be reproduced in an editable and scalable manner within the

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algorithmic framework; Qiangzhi Zuo and Junwei Zhang [3] have taken the sports intangible heritage of the Jiangsu section of the Grand Canal as the object, using the cultural space theory to analyze the interactive relationship between the digital dissemination path and regional cultural identity. Li Li [4] has focused on the way that the digitalization of intangible heritage integrates into urban public spaces in Hainan. Nan Li and Xiaofen Ji [5] have brought cultural heritage digitization into university ideological and political classes. Tianni Yang [6] has started from visual recognition systems and cultural tourism product design, exploring how digitization can build a bridge between regional brands and cultural experiences; Helena García Mieres and other scholars [7] have pointed out through rural area cases that the combination of digitization and social innovation helps to narrow the "participation gap" in the inheritance of rural cultural heritage between urban and rural areas and between generations. These studies show that the digitization of intangible cultural heritage has expanded from a single technical topic to a comprehensive agenda that drives industries, education and social development.

In terms of tangible cultural heritage and historical environment, related research also shows a trend of "technological depth + scenario expansion". Siqi Wang et al. [8] established an identification, evaluation and digital modeling method for historical buildings of the Quanzhou World Cultural Heritage based on deep learning algorithms, combining image recognition with 3D reconstruction to support protection decisions; Pedro Santos et al. [10] proposed autonomous 3D digitalization technology, which can adapt to various individual cultural relics, laying the foundation for large-scale collection of high-precision models; The 30th CIPA Academic Conference [11] clearly proposed that we should move from "digital recording" to "data-driven protection", emphasizing that digital achievements should play a role in decision-making processes such as disease diagnosis and intervention plan selection. Heritage BIM and digital twins have gradually become important tools in the field of architectural heritage. Ahmad Baik [13] constructed a Heritage BIM full-process methodology for historical market districts, and Dang Xinyuan et al. [20] conducted a systematic review of the digital twin application in China's World Cultural Heritage sites, demonstrating the technical path from geometric modeling to operation monitoring and scenario simulation. Correspondingly, in the museum and destination management fields, Zirui Wang and Jie Meng [12] constructed an analytical framework for the role of museum digitization on audiences from four dimensions: "cognitive identification - technical proxy - cultural symbol - public participation", while Li Yao et al. [14] proved that the digitization of cultural heritage destinations will significantly influence tourists' attitudes and behaviors through "constructive realism" and "technology - destination compatibility".

Meanwhile, more and more studies have begun to assess the actual effectiveness of cultural heritage digitization from the perspectives of "sustainability" and "governance". Zi Yan et al. [9] identified the key indicators that affect the effectiveness of digital dissemination of intangible cultural heritage through qualitative interviews, advocating a shift from "click-through rate" to "quality of participation" and "depth of cultural understanding"; Branislav Sančanin and Aleksandra Penjišević [15] demonstrated in the Serbian context that systematic digitization work and innovative promotion techniques have quantifiable effects on enhancing the national cultural image; Ben Yahia Karim and Bouslama Fedia [16] proposed in Tunisia that in the post-crisis context, the digitization of cultural heritage and innovative promotion are important levers for driving the recovery of destinations. Regarding the relationship between "cultural heritage - identity - education", Delfín Ortega Sánchez and Amparo Bernal López Sanvicente [17] developed the DICHIE tool to evaluate the suitability of digitized cultural heritage resources in identity construction and educational contexts; Muangasame Kaewta and Tan Eunice [18] proposed the "phygital rural cultural heritage" model, indicating that the

integration of virtual and physical elements can enhance the resilience and recovery capacity of rural destinations; Sakoumaki M.C. et al. [19] demonstrated in the practice of the Delphi Archaeological Museum the potential of advanced digital technologies to build a closed loop between the display of cultural relics, knowledge dissemination and protection management. Overall, existing studies have accumulated rich results in the digital expression of intangible cultural heritage and architectural heritage, intelligent generation, BIM/digital twin modeling, innovative museum narrative, and destination marketing, but they are more focused on "how the content is digitized", "how tourists are attracted", and "how the brand is shaped".

From the above-mentioned literature, it can be observed that an unanswered question is: Under the overall trend of "integration of virtual and real", how to simultaneously consider the digital protection design of cultural heritage and the innovation of tourism management models within the same technical framework, integrating 3D models, environmental monitoring, visitor behavior data, and management rules into a computable, verifiable, and iterative operational mechanism. In the existing studies, regarding how "virtual - real - human - management" can form a closed loop through data, how to embed protection goals into exhibition and crowd flow organization design using a rule engine, and how to construct an evaluation model that can quantify the synergy degree of the "safety - experience - efficiency" triple goals, there is still relatively weak content. Based on this, this paper takes "digital protection design of cultural heritage in a virtual-real integration display environment and new tourism management model" as the theme, at the system architecture level, builds a three-layer platform of "perception and collection - data and services - application and display", and proposes an integrated modeling method of object - space - behavior - rules; at the protection practice level, designs "remote viewing main line + virtual substitution", "physical buffer + environmental warning" for virtual-real integration protection schemes, and links them with the rule engine; at the management evaluation level, introduces visitor behavior data and multi-dimensional indicator systems, constructs a comprehensive evaluation model of operational efficiency, visitor experience, and protection synergy, and provides quantitative verification through pilot projects of typical heritage sites, aiming to provide a replicable and scalable framework and evidence for the integrated upgrade of cultural heritage digital protection and tourism management.

2 Related Works

2.1 Integration of reality and virtuality showcases the system architecture and cultural heritage scene modeling

The design concept of the integration of reality and virtuality display system is to simultaneously support three goals on the same technical platform: "cultural heritage ontology protection, digital content display, and tourism site management". To achieve this, it is necessary to integrate data flow, business flow and control flow at the system level, realize precise mapping of real scenes and virtual scenes at the spatial level, and use a unified scene model to carry out subsequent display design and management decisions.

In terms of the overall architecture, this research adopts the technical route of "three-layer architecture + unified message bus". The bottom layer is the perception and collection layer, which undertakes continuous observation of the real heritage environment, including geometric collection devices such as 3D laser scanning, tilt photography, structured light cameras, as well as IoT sensors such as temperature and humidity, lighting, vibration, noise, passenger flow statistics and positioning terminals; the middle layer is the data and service layer, which is responsible for cleaning, coordinate unification and semantic annotation of multi-source data, constructing the object library of cultural heritage, the spatial scene library, the visitor behavior

library and the protection rule library, and providing virtual-real mapping services, rule reasoning services and interface management; the upper layer is the application and display layer, which provides virtual-real integrated navigation terminals, visitor-side mobile applications or mini-programs, management cockpit, operation and maintenance monitoring and data analysis tools for different roles, and realizes integrated support for display, management and decision-making. The schematic diagram of the system architecture is shown in Figure 1.

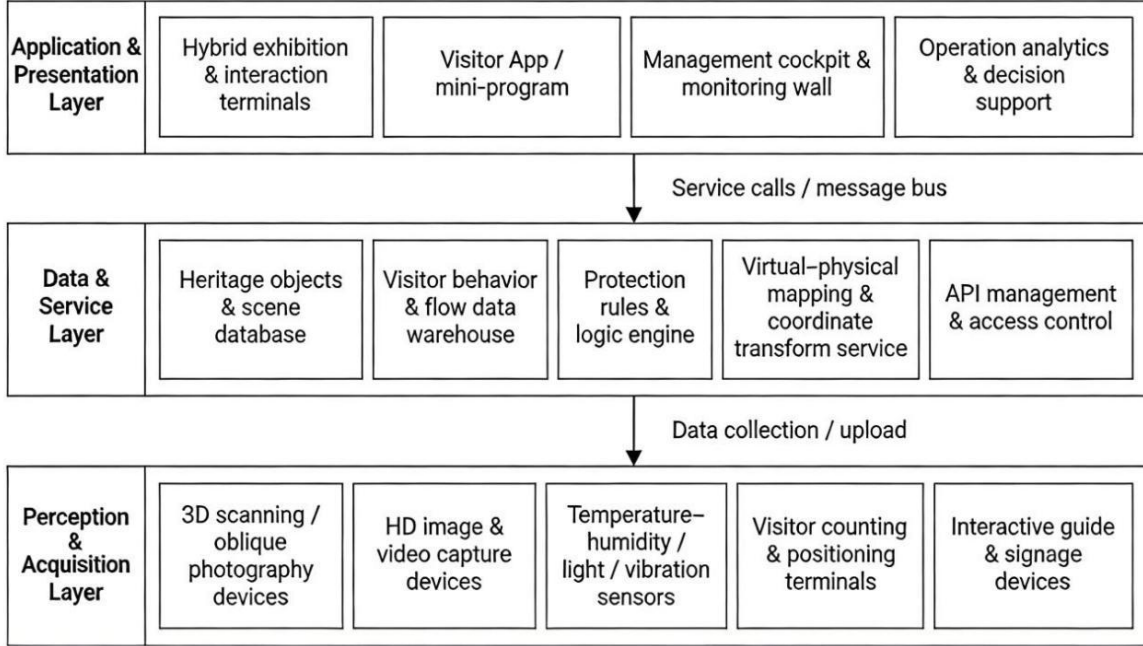


Figure 1: Schematic Diagram of the Overall Architecture of the Real-World and Virtual-World Fusion Display System.

Based on the above framework, this study abstracts the cultural heritage scenarios into a graph model composed of object nodes and relationship edges. Let the set of heritage objects be:

$$O = \{ o_i \mid i = 1, 2, \dots, N_O \} \quad (1)$$

The spatial unit set is:

$$S = \{ s_j \mid j = 1, 2, \dots, N_S \} \quad (2)$$

The passage path set is:

$$P = \{ p_k \mid k = 1, 2, \dots, N_P \} \quad (3)$$

The viewpoint and viewshed set is:

$$V = \{ v_l \mid l = 1, 2, \dots, N_V \} \quad (4)$$

The device node set is:

$$D = \{ d_m \mid m = 1, 2, \dots, N_D \} \quad (5)$$

Then the overall scene model can be formally represented as a directed multi-relational graph:

$$\mathcal{G} = (\mathcal{V}, \mathcal{E}), \quad \mathcal{V} = O \cup S \cup P \cup V \cup D \quad (6)$$

where V is the node set, E is the edge set, and the types of edges include "located", "adjacent", "reachable", "monitored", "interacted", etc., to express the topological relationships and functional dependencies between different objects.

For any heritage object o_i , to describe its comprehensive characteristics related to protection design, a state vector is introduced:

$$f(o_i) = [d_i, h_i, e_i, r_i]^T \quad (7)$$

Among them, d_i represents the minimum safe distance between the object and the accessible area for tourists, h_i represents the disease or vulnerability level (for example, discrete values ranging from 1 to 5), e_i reflects environmental sensitivity (corresponding to the range of allowable environmental indicators such as temperature, humidity, and illumination), and r_i represents the protection level or management priority. The state vector $f(o_i)$ will be linked with the rule engine in the subsequent chapters to trigger different intensities of protection measures and display constraints.

To achieve an accurate mapping between the real heritage space and the virtual scene, a unified coordinate transformation model needs to be constructed. Let the homogeneous coordinates of a certain point in the real space be:

$$p_r = [x_r, y_r, z_r, 1]^T \quad (8)$$

The coordinates of the corresponding points in the virtual scene are:

$$p_v = [x_v, y_v, z_v, 1]^T \quad (9)$$

Then the relationship between the two can be expressed as:

$$p_v = T p_r = S R p_r + t \quad (10)$$

Among them, R is the 3D rotation matrix, S is the scaling matrix, t is the translation vector, and T is the overall homogeneous transformation matrix. Using the set of control points $\{p_r^{(n)}, \hat{p}_v^{(n)}\}_{n=1}^N$ deployed on-site, the optimal transformation matrix can be obtained through least squares estimation:

$$T^* = \arg \min_T \frac{1}{N} \sum_{n=1}^N \left\| T p_r^{(n)} - \hat{p}_v^{(n)} \right\|_2^2 \quad (11)$$

This process ensures that the positions of heritage objects, spatial boundaries and device nodes in the virtual scene are consistent with those in the real space, providing a geometric basis for subsequent path planning, field of view analysis and risk assessment based on the virtual scene.

On the basis of coordinate unification, it is necessary to quantitatively evaluate the mapping accuracy to balance the modeling accuracy and real-time rendering cost. Set at the sample point set, the points obtained through mapping are $p_v^{(n)}$, and the high-precision reference model or

precise measurement data is taken as the "true value" point $\hat{p}_v^{(n)}$. Then, the mean square mapping error is defined as:

$$E_{\text{map}} = \frac{1}{N} \sum_{n=1}^N \left\| p_v^{(n)} - \hat{p}_v^{(n)} \right\|_2^2 \quad (12)$$

When $E_{\text{map}} \leq \varepsilon$ (where ε is the preset allowable threshold), it can be considered that the geometric consistency meets the accuracy requirements for protection and display.

To balance the detail presentation and system performance, this study introduces a hierarchical detail (Level of Detail, LOD) strategy in scene modeling. For the same heritage object o_i , different precision geometric models are pre-built:

$$\{ M_i^{(l)} \mid l = 1, 2, \dots, L \} \quad (13)$$

The corresponding number of polygons is $M_i^{(l)}$. Based on the Euclidean distance d_i between the current viewpoint and the object's center of gravity, the LOD selection function is defined:

$$l_i(d_i) = \begin{cases} 1, & 0 < d_i \leq d_1, \\ [3\text{pt}]2, & d_1 < d_i \leq d_2, \\ \vdots & \\ L, & d_{L-1} < d_i \end{cases} \quad (14)$$

And if $M_i(l_i(d_i))$ is enabled during rendering, the total number of polygons in the entire scene at a certain moment is:

$$N_{\text{poly}} = \sum_i n_i^{(l_i(d_i))} \quad (15)$$

Under the premise of meeting the geometric accuracy constraints specified by equation (15), by adjusting the complexity of each level of the model $M_i^{(l)}$ and the distance threshold $\{d_1\}$, N_{poly} can be controlled within the range that the rendering pipeline can handle, thereby ensuring that the virtual-real fusion display remains smooth and stable under peak passenger flow conditions.

Cultural heritage scene modeling not only needs to represent the static spatial structure, but also serves for tourist behavior analysis and tourism management. At discrete time step t , tourist behavior is recorded as a trajectory sequence $\{q^{(u)}(t)\}$, where $q^{(u)}(t)$ is the position of tourist u in the virtual scene coordinate system. Through coordinate transformation, it can be attributed to the spatial unit set S , thereby obtaining the passenger flow of spatial unit s_j within the time interval ΔT :

$$\lambda_j(\Delta T) = \sum_u \sum_{t \in \Delta T} \mathbb{I}[q^{(u)}(t) \in s_j] \quad (16)$$

where $\mathbb{I}[\cdot]$ is the indicator function. When the safety carrying capacity limit C_j of each spatial unit is known, the congestion index $\rho_j(\Delta T)$ can be further constructed:

$$\rho_j(\Delta T) = \frac{\lambda_j(\Delta T)}{C_j} \quad (17)$$

When $\rho_j(\Delta T)$ exceeds the set threshold θ , the system can achieve real-time dynamic control based on the scene model by applying and triggering flow-limiting prompts, recommending alternative routes, or adjusting the virtual tour content.

Through the above system architecture design and scene modeling, this research has formed an integrated digital foundation of "object - space - behavior - rule" at the data and service layer, providing a unified modeling basis and computable support for the subsequent virtual-real integration protection design, tourist behavior analysis, and the construction of new tourism management models.

2.2 Digital collection, protection process and rule coding of cultural heritage

In the environment of integrating virtuality and reality, the digital collection of cultural heritage is no longer just a one-time "modeling task", but a continuous process that encompasses "current situation investigation - detailed collection - data processing - risk assessment - rule implementation". Only by integrating geometric form, material texture, damage information, environmental monitoring data, and maintenance management records into a set of computable data structures, and further converting them into executable protection rules, can the virtual-real integration display system truly undertake the functions of "protection + management", rather than merely being "attractive" digital exhibitions.

Based on the constructed scene model, this study abstracts the digital collection results of each heritage object o_i into a multi-dimensional data vector:

$$x_i = \begin{bmatrix} g_i \\ t_i \\ s_i \\ e_i \\ m_i \end{bmatrix} \quad (18)$$

Among them, " g_i " represents geometric accuracy (such as point cloud density, mesh resolution, etc., as a comprehensive indicator), " t_i " represents texture and image quality (resolution, color fidelity, noise level, etc.), " s_i " represents the completeness of structural and defect information (cracks, weathering, damage, etc. annotation), " e_i " represents the completeness and temporal continuity of object-related environmental monitoring data, and " m_i " represents the completeness of repair and management records. These five components jointly depict the basic state of the object at the "digital level".

To facilitate intuitive comparison of the digital quality of different objects in protection decisions, normalization processing and weighted aggregation are introduced to construct a digital quality score Q_i :

$$Q_i = \sum_{p=1}^5 w_p \tilde{x}_{i,p}, \quad \sum_{p=1}^5 w_p = 1, w_p \geq 0 \quad (19)$$

Among them, $\tilde{x}_{i,p}$ represents the result after the $\tilde{x}_{i,p}$ component is standardized by range or normalized by quantile, and falls within the [0,1] range. w_p is the importance weight of each

dimension. By setting the quality threshold Q_{thr} , the objects can be classified into different levels such as "high-quality digitalization", "usable but requires supplementary collection", "not suitable for detailed analysis at present", etc., providing basic constraints for subsequent display design and protection rules.

Only the digital quality is not enough. The risk level of the object needs to be quantified as well, so as to truly drive the protection process. Combining the state vector $f(o_i)$ and the crowding degree index $\rho_j(\Delta T)$ of the spatial unit where the object is located, this paper constructs the object comprehensive risk index R_i :

$$R_i = \alpha h_i + \beta (1 - e_i') + \gamma \rho_i \quad (20)$$

Among them, h_i represents the disease or vulnerability level of the object, and e_i' represents the environmental safety degree (obtained by comparing the monitoring data of temperature, humidity, illumination, vibration, etc. with the allowable thresholds, with a larger value indicating a more stable environment). ρ_i is mapped from the crowding degree $\rho_j(\Delta T)$ of the spatial unit where the object is located. α , β , and γ are weight parameters. The higher the value of R_i , the more unfavorable the risk combination state of the object is, and it requires priority protection and intervention.

From a process perspective, digital collection and protection are not two disconnected chains, but should be connected through algorithmic description to form a complete mapping from "raw data to executable rules". Let the set of all original collection data of the objects be \mathcal{D}^{raw} , including on-site three-dimensional data, images, monitoring data, and document materials, etc. After processing, the set of states that can be used for protection decisions is \mathcal{S}^{prot} . Then, the overall process can be abstracted as:

$$F_{prot}: \mathcal{D}^{raw} \rightarrow \{x_i, f(o_i), Q_i, R_i\}_{i=1}^{N_o} \in \mathcal{S}^{prot} \quad (21)$$

Among them, the mapping F_{prot} includes multiple steps such as collection, preprocessing, registration, reconstruction, annotation, fusion, and evaluation.

In the actual engineering deployment, the above mapping is refined into a set of repeatable algorithmic processes. To facilitate the understanding and reuse by different project teams, this study provides the following step description:

Algorithm steps (Digitalization and protection process of cultural heritage)

1. Object and Area Inventory: Based on the scene diagram G , combined with expert opinions and management requirements, select the key object set $O^* \subseteq O$ and the key space unit set $S^* \subseteq S$, and form the priority list for digitalization and protection work in this stage.

2. Collection Scheme Design: For each object $o_i \in O^*$, according to its scale, material, location conditions and vulnerability degree, configure appropriate collection equipment and precision parameters, forming the collection parameter set Φ_i (including point cloud resolution, image resolution, monitoring frequency, etc.).

3. On-site Data Collection: Execute multi-source data collection according to Φ_i , generate the original data package \mathcal{D}^{raw} , and simultaneously record the collection time, coordinate reference, equipment number and operator information, providing a basis for subsequent traceability and quality control.

4. Data Preprocessing and Registration: Perform noise reduction, filtering, resampling, coordinate registration and occlusion compensation on \mathcal{D}^{raw} , obtaining point cloud, mesh and texture data in a unified coordinate system, and forming \mathcal{D}^{proc} .

5. 3D Reconstruction and Semantic Annotation: Based on \mathcal{D}^{proc} , geometric reconstruction, texture mapping, and normal calculation are carried out. On this basis, semantic annotations are

made for disease features such as cracks, weathering, salt erosion, and stains, and the object state $f(o_i)$ and data vector x_i are updated.

6. Environmental and Monitoring Data Fusion: The historical environmental monitoring sequence $\{E_j(t)\}$ of the spatial unit s_j where the object is located is associated with the relevant entries in the repair record library to the object o_i . The environmental safety degree e_i' , digital quality score Q_i , and risk index R_i are calculated.

7. Risk Classification and Strategy Binding: Based on the combination of Q_i and R_i , the object is divided into several grades using multi-threshold partitioning, such as: high-risk high-quality (suitable for virtual substitution display), high-risk low-quality (prioritize supplementary collection and control flow), and low-risk high-quality (suitable for deep display), and the grade information is written into the object metadata.

8. Archiving and Interface Release: The key metadata, logs, and evaluation results collected and processed throughout the process are archived uniformly to form a traceable digital archive; at the same time, through the interface of the data and service layer, the structured results are opened to the display subsystem and the management cockpit, preparing for the call of the rule engine.

On top of the above process, the protection and management requirements need to be further formalized into executable rules. This paper adopts the "condition–action" (Condition–Action) expression method, and represents a single protection rule r_k as:

$$r_k: C_k \Rightarrow A_k \quad (22)$$

Among them, the condition part C_k can be written as the conjunction of a set of atomic conditions:

Each $c_{k,m}$ is usually a threshold judgment regarding variables such as Q_i , R_i , $\rho_j(\Delta T)$, etc. For example:

$$C_k = c_{k,1} \wedge c_{k,2} \wedge \dots \wedge c_{k,M_k} \quad (23)$$

Indicates "the object has a high risk and the digital quality has reached a certain level"; the action part A_k is a combination of a set of protection and management operations, such as limiting the maximum carrying capacity of the space unit where the object is located, adjusting the virtual guided tour path, triggering on-site inspection tasks, and placing warnings at the top of the management cockpit, etc. The rule set can be uniformly expressed as:

$$C_k = c_{k,1} \wedge c_{k,2} \wedge \dots \wedge c_{k,M_k} \quad (24)$$

To ensure the consistency and interpretability of the rules during the system operation, a lightweight rule engine is built into the data and service layers. Its core logic can be described in the following pseudo-code:

Algorithm 1 ProtectionRuleInference

Input:

O // Collection of legacy objects

R_set // Set of rules

State(o) // Returns the state vector $f(o)$ and data vector $x(o)$ of object o

Context(o) // Returns the environment and passenger flow information of the spatial unit

where object o is located Output:

Actions // Queue of protection actions to be executed 1: Actions $\leftarrow \emptyset$

2:for each o in O do

3:(f_o, x_o) \leftarrow State(o)

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4:ctx_o ← Context(o)
5:for each r in R_set do
6:if CondSatisfied(r.C, f_o, x_o, ctx_o) then
7:act_list ← r.A
8:Actions ← Actions ∪ {(o, act_list)}
9:end if
10:end for
11:end for
12:ResolveConflicts(Actions) // Conflict resolution and priority sorting
13:Execute(Actions) // Dispatch to display and management subsystems

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Among them, CondSatisfied is used to determine whether the current object state and the environmental context meet condition C_k ; ResolveConflicts, when different rules propose conflicting actions for the same object, sorts and resolves the conflicts based on the object's protection level r_i , risk index R_i , and operational constraints; Execute is responsible for mapping the abstract action list to specific system operations, such as updating the virtual tour path table, modifying the passenger flow threshold of the spatial unit, and pushing on-site alarm messages, etc.

Through the above digital collection index system, risk assessment formula, process algorithmic description, and the pseudo-code implementation of the rule engine, this section has completed the coding loop from "original collected data" to "executable protection rules", making the cultural heritage in the virtual-real integrated display environment no longer just a "passive display object", but has dynamic, perceptible, assessable, and controllable protection and management mechanisms on the digital platform.

2.3 Digital collection, protection process and rule coding of cultural heritage

In the environment where virtual and real elements are integrated, tourists continuously interact with the system through guide apps, electronic tickets, interactive screens, AR/VR devices, etc. Their behavioral trajectories, distribution of stays, interaction frequencies and subjective feedback can all be recorded, forming a data chain that runs through "entering the park - touring - interacting - leaving the park". If this data chain can be systematically collected, organized and modeled, it will be possible to conduct quantitative evaluations of tourism management levels from three dimensions: operational efficiency, tourist experience and protection constraints, and provide a basis for optimizing subsequent management strategies.

From the perspective of data collection, first, define the set of tourists:

$$U = \{u_1, u_2, \dots, u_{N_U}\} \quad (25)$$

At discrete time step t , the position of tourist u in the virtual scene coordinate system is denoted as $q(u)(t)$, and it can be associated with a certain spatial unit s_j through coordinate mapping. Within the given evaluation time window ΔT , the core behavioral statistics of tourist u can be compressed into a behavioral feature vector:

$$b_u(\Delta T) = [T_u^{stay}, N_u^{node}, N_u^{inter}, L_u^{path}]^T \quad (26)$$

Among them, T_u^{stay} represents the total stay duration, N_u^{node} is the number of actual visited spatial nodes, N_u^{inter} is the number of interactions with the system (scanning, triggering AR, operating touch screen, etc.), and L_u^{path} is the length of the tour path or the number of steps. By aggregating and clustering $\{b_u(\Delta T)\}$, typical tour patterns can be identified, such as "fast

browsing type", "deep experience type", "random wandering type", etc., providing a basis for the design of virtual and real guided tour routes and information push strategies.

At the path efficiency level, to measure whether tourists have "ineffective detours" within the scenic area, a relative detour rate indicator can be defined. Let L^* be the ideal length of the recommended path under a certain typical tour task, and L_u^{path} be the actual path length of tourist u . Then, the detour rate can be expressed as:

$$\delta_u = \frac{L_u^{path} - L^*}{L^*} \quad (27)$$

When $\delta_u > 0$, it indicates that there are varying degrees of detouring or even getting lost. The larger the δ_u value, the less adequate the path design and guided navigation are. When δ_u approaches 0, it means that the tourist's travel path is in good agreement with the recommended path, and the guided tour and on-site signage system have played a good role.

At the level of space management, the regional load situation can be described by the aforementioned passenger flow $\lambda_j(\Delta T)$ and congestion degree $\rho_j(\Delta T)$. To depict the balance of overall space utilization, a time-space utilization balance index can be constructed. Assuming that within the same time window ΔT , the average congestion degree of each spatial unit is $\hat{\rho}_j$, and it is normalized to obtain $\{\hat{\rho}_j\}$, then the balance index can be defined as:

$$F_{space}(\Delta T) = 1 - \frac{1}{2} \sum_{j=1}^{N_s} \sum_{k=1}^{N_s} \|\hat{\rho}_j - \hat{\rho}_k\| \quad (28)$$

Among them, $\rho^{\wedge}j$ is the result after ρ_j is linearly normalized and falls within the range of [0,1]. The closer $F_{space}(\Delta T)$ is to 1, the more uniform the passenger flow distribution among different spatial units is, and the more effective the diversion guidance is; if the index significantly decreases, it indicates that some areas are overloaded while others are idle, and there are problems with unreasonable distribution of routes and resources.

In order to evaluate the overall performance of tourism management within a time window as a whole, multiple indicators from the three dimensions of operational efficiency, visitor experience and protection constraints need to be unified into a single evaluation vector. Let the management evaluation index vector be constructed within the time window ΔT :

$$z(\Delta T) = [z_1, z_2, \dots, z_M]^T \quad (29)$$

Among them, the various components can include: average queuing time, maximum queuing time, peak congestion level, space utilization balance factor F_{space} , average stay duration, tourist satisfaction score, knowledge acquisition score, complaint rate, accident/warning event count, and the number of times protection-related rules are triggered. Due to the different units of different indicators and their positive or negative nature, standardization needs to be performed first. For each indicator z_m , the following transformation is applied:

For positive indicators where "the larger the better", use:

$$\tilde{z}_m = \frac{z_m - z_m^{\min}}{z_m^{\max} - z_m^{\min}} \quad (30)$$

For the reverse indicator of "the smaller the better", the following approach is adopted:

$$\tilde{z}_m = \frac{z_m^{\max} - z_m}{z_m^{\max} - z_m^{\min}} \quad (31)$$

Among them, z_m^{\max} and z_m^{\min} represent the maximum and minimum values of the indicator within the reference period or in the historical samples. After standardization, a dimensionless indicator vector $\tilde{z}(\Delta T)$ can be obtained.

Based on this, a weight vector $\omega = [\omega_1, \dots, \omega_M]T$ is introduced, where $\sum_{m=1}^M \omega_m = 1$ and $\omega_m \geq 0$, to obtain the comprehensive evaluation score of tourism management:

$$\begin{aligned} E_{\text{eff}}(\Delta T) &= \sum_{m \in J_{\text{eff}}} \omega_m \tilde{z}_m(\Delta T), \quad E_{\text{exp}}(\Delta T) \\ &= \sum_{m \in J_{\text{exp}}} \omega_m \tilde{z}_m(\Delta T) \end{aligned} \quad (32)$$

Among them, ω can be determined through expert scoring method, analytic hierarchy process or entropy weight method; the higher $E_{\text{mgmt}}(\Delta T)$, the closer the tourism management within the time window is to the expected goal. According to research needs, the comprehensive evaluation can also be divided into "operation efficiency sub-score" and "tourist experience sub-score", for example:

$$\begin{aligned} E_{\text{eff}}(\Delta T) &= \sum_{m \in J_{\text{eff}}} \omega_m \tilde{z}_m(\Delta T), \quad E_{\text{exp}}(\Delta T) \\ &= \sum_{m \in J_{\text{exp}}} \omega_m \tilde{z}_m(\Delta T) \end{aligned} \quad (33)$$

Among them, E_{eff} and E_{exp} are the index sets belonging to the "efficiency dimension" and "experience dimension" respectively.

From the perspective of system implementation, the process of collecting tourist behavior data and evaluating it can be summarized as several repeatable steps:

(1) Determine the evaluation time window and spatial division. Based on the opening hours of the scenic area, the tourist flow cycle and management requirements, the operation period is divided into several time windows $\{\Delta T_q\}$, and the set of spatial units S involved in the evaluation is clearly defined in the scenario model.

(2) Collect location and interaction logs. Through positioning terminals, gate card reading records, Wi-Fi/Bluetooth probes, mobile SDK and interaction device logs, the entry time, departure time, discrete location sequence $\{q(u)(t)\}$ and interaction event sequence (including timestamps and object/device IDs) of tourists are collected.

(3) Clean and map behavioral data. Perform time synchronization, noise removal and abnormal trajectory elimination on the original logs, map each location point to the corresponding spatial unit s_j , and associate the interaction events with specific heritage objects or exhibits to form a structured behavioral data set.

(4) Calculate statistics at the object layer and spatial layer. Based on basic statistics such as $b_u(\Delta T)$, $\lambda_j(\Delta T)$, $\rho_j(\Delta T)$, calculate the operation pressure index $\rho_j(\Delta T)$ and spatial utilization balance $F_{\text{space}}(\Delta T)$ of each spatial unit, and combine the risk index R_i to analyze the triggering situation and effectiveness of protection rules under different tourist flow states.

(5) Construct the evaluation index vector and standardize. According to the pre-designed

index system, calculate the index vector $z(\Delta T_q)$ for each time window ΔT_q , and standardize the positive and reverse indicators in it using formulas (30) and (31), obtaining $\tilde{z}(\Delta T_q)$.

(6) Calculate the comprehensive and fractal evaluation scores. Using the weight vector ω and formulas (32) and (33), calculate the comprehensive evaluation score $E_{mgmt}(\Delta T_q)$ and sub-scores such as efficiency and experience, and draw trends on the time axis to compare the performance of different management strategies or different exhibition areas, providing a basis for subsequent management optimization.

Based on the above data flow and calculation process, an overall framework of the "tourism management evaluation model driven by tourist behavior data" can be constructed. Its logical structure is shown in Figure 2.

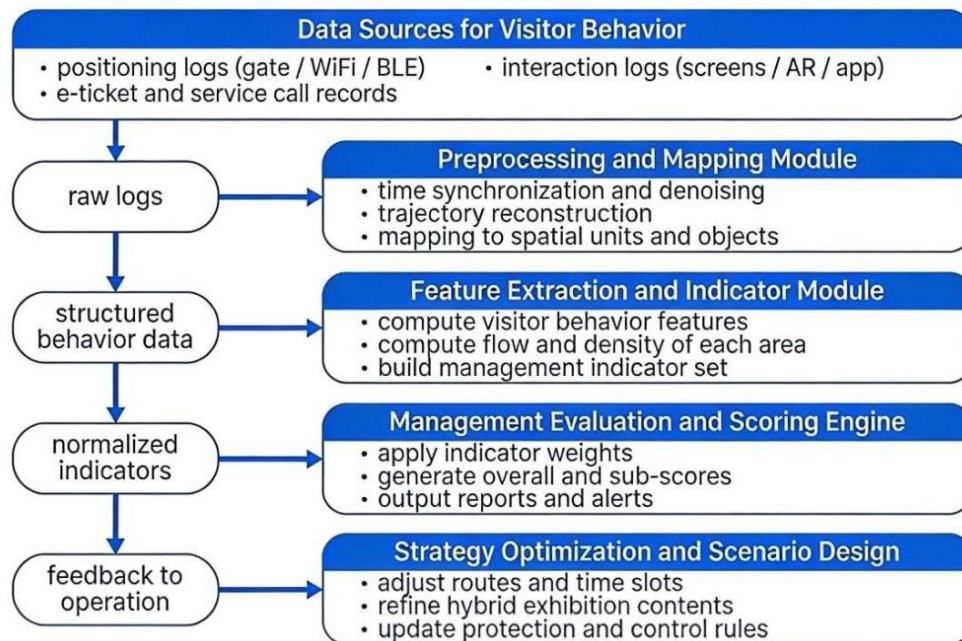


Figure 2: Illustration of the construction of a tourism management evaluation model driven by tourist behavior data.

In the data and service layer, the aforementioned modules are deployed in the form of services. The application and presentation layer periodically invokes the evaluation results through interfaces and presents the indicators such as E_{mgmt} , E_{eff} , and E_{exp} in chart form to the managers. To facilitate the engineering implementation, the entire process can be abstracted as the "Visitor Behavior Collection and Management Evaluation Algorithm", and its pseudo code is as follows.

Algorithm 2 VisitorBehaviorCollectionAndEvaluation

Input:

U // visitor set

S // spatial unit set

Windows // time windows $\{\Delta T_q\}$

LogsPos // raw positioning logs

LogsInt // raw interaction logs

EnvData // environment & flow data

Weights // weight vector ω

Output:

Scores // $\{\Delta T, E_{mgmt}, E_{eff}, E_{exp}\}$

```

1: Scores  $\leftarrow \emptyset$ 
2: for each  $\Delta T$  in Windows do
3:   BehaviorSet  $\leftarrow \emptyset$ 
4:   for each  $u$  in  $U$  do
5:     traj_u  $\leftarrow$  ExtractTrajectory(LogsPos,  $u$ ,  $\Delta T$ )
6:     inter_u  $\leftarrow$  ExtractInteractions(LogsInt,  $u$ ,  $\Delta T$ )
7:     b_u  $\leftarrow$  ComputeBehaviorVector(traj_u, inter_u)
8:     BehaviorSet  $\leftarrow$  BehaviorSet  $\cup$   $\{(u, b_u)\}$ 
9:   end for
10:  for each  $s$  in  $S$  do
11:     $(\lambda_s, \rho_s) \leftarrow$  ComputeFlowDensity(LogsPos,  $s$ ,  $\Delta T$ )
12:    P_s  $\leftarrow$  ComputePressure( $\lambda_s, \rho_s$ , EnvData)
13:  end for
14:  z  $\leftarrow$  BuildIndicatorVector(BehaviorSet, {P_s}, EnvData,  $\Delta T$ )
15:  z_norm  $\leftarrow$  NormalizeIndicators(z)
16:   $(E_{\text{mgmt}}, E_{\text{eff}}, E_{\text{exp}}) \leftarrow$  ScoreManagement(z_norm, Weights)
17:  Scores  $\leftarrow$  Scores  $\cup$   $\{(\Delta T, E_{\text{mgmt}}, E_{\text{eff}}, E_{\text{exp}})\}$ 
18: end for
19: return Scores

```

Through the above formulas, steps and pseudo-code, the virtual-real integration display system can, within the closed loop of "real-time perception - quantitative evaluation - strategy feedback", convert tourist behavior data into actionable management decision-making basis, providing verifiable and traceable quantitative support for the proposed new tourism management model in the subsequent text.

3 Results

3.1 Analysis of the Design and Display Effects of the Integration of Virtual and Physical Protection for Cultural Heritage

Based on the system architecture and digital acquisition, as well as rule coding in the previous two chapters, this section analyzes the implementation results of the virtual-real integration scheme from two dimensions: "protection effectiveness" and "display effect". The research takes a typical cultural heritage site as the empirical object, comparing the changes in key indicators before and after the implementation of the virtual-real integration protection design, and focusing on the following aspects: (1) Whether the flow intensity and stay behavior in sensitive areas have been effectively controlled; (2) Whether the risk events of the cultural relics have significantly decreased; (3) Under the premise of reducing risks, whether the depth of display and the visitor experience have still been improved.

From the design perspective, the virtual-real integration protection scheme is not simply a simple superposition of virtual content, but rather, based on principles such as "layered display of virtual and real, graded control of movement lines, virtual substitution for viewing, and environmental warning linkage", a set of "display - protection - management" integrated design framework has been constructed. The specific design elements and their implementation methods are shown in Table 1.

Table 1: Comparison Table of Elements and Implementation Methods for Integrated Real-World and Virtual-World Protection Design.

Module	Design elements	Implementation approach	Role in protection and presentation
Route and spatial organization	Hierarchical main and secondary routes; buffer nodes	Set sensitive areas as “view-only” viewing points; guide the main route to form a ring-shaped flow around the periphery, with secondary routes leading to non-sensitive zones	Reduce dwelling and congestion in sensitive areas, avoid direct crowd pressure on the artifacts, while maintaining the integrity and continuity of the overall visiting route
Virtual content configuration	Virtual reconstruction, detail magnification, multi-view rendering	Deploy high-precision virtual reconstructions and detail magnification interfaces in secondary spaces or online portals, guiding visitors to conduct close-up observation in the “virtual space”	Use digital details to substitute for physical close-up viewing, supplementing information richness and depth of appreciation without increasing physical risks to heritage objects
Physical separation and buffer zones	Safety distance control; unobtrusive isolation facilities	Use low showcases, glass balustrades, floor markings and similar measures to define the minimum distance between visitors and artifacts, and set small buffer platforms at key nodes	Form a soft boundary without significantly disrupting spatial perception, effectively reducing direct risks such as touching, bumping and collision
Environmental monitoring and early warning	Integrated monitoring of temperature–humidity, light and visitor flow	Deploy environmental and visitor flow sensors in sensitive areas and link monitoring data to the rule engine so that once thresholds are exceeded, flow control or alerts are automatically triggered	Achieve dynamic sensing and rapid response to environmental and crowd changes, preventing “compounded risks” from escalating rapidly in a short period of time

As can be seen from Table 1, the integrated protection design actually achieves synergy at four levels: "space layout - virtual content - physical isolation - environmental monitoring". It "thins out" risks through spatial organization and physical isolation, "shifts" viewing demands through virtual content, and "moves forward" sudden risks through monitoring and early warning, enabling the depth of display and the intensity of protection to be considered simultaneously in the same design.

To verify the design effect, this study continuously monitored the key indicators related to protection before and after implementation, including peak flow density in sensitive areas, average stay time, close contact incidents, and the number of environmental indicators exceeding the standard, and some statistical results are shown in Table 2.

Table 2: Comparison of Protection-related Indicators Before and After Implementation of the Fusion of Factual and Imaginary Elements in Protection Design.

Indicator	Before implementation	After implementation	Change
Peak visitor density in sensitive areas (persons/m ²)	3.2	2.1	↓34.4%
Average dwell time in sensitive areas (seconds/person)	165	98	↓40.6%
Close-contact incidents with artifacts (cases/day)	5.3	1.2	↓77.4%
Number of environmental threshold exceedances (times/month)	12	4	↓66.7%

Monitoring data shows that after the introduction of the virtual-real integration protection design, the peak crowd density in sensitive areas has significantly decreased, and the average stay time has shortened. This indicates that the flow line arrangement of "remote viewing main line + virtual substitution" effectively reduces the gathering and stagnation around the cultural relics themselves. The significant decrease in close-contact incidents reflects the protective effect of physical isolation and soft boundaries. The number of environmental indicators exceeding the standard has decreased, indicating that the environmental monitoring and early warning mechanism has played a regulatory role during peak passenger flow periods. Overall, the protection-related indicators show a relatively stable improvement trend.

"Protecting more safely" alone is not sufficient to support the reform of the management model. The more crucial value of the virtual-real integration plan lies in: while reducing risks, whether the level of detail displayed and the learning experience of tourists are simultaneously improved. Therefore, this article conducts a comparative evaluation of the display effect from four perspectives: in-depth explanation of reach rate, interaction participation rate, overall satisfaction of tourists and knowledge gain. The results are shown in Table 3.

Table 3: Comparison of display and experience indicators before and after the implementation of the integration of reality and virtuality protection design.

Indicator	Before implementation	After implementation	Change
Reach rate of in-depth interpretation (%)	46.8	71.5	↑24.7 percentage points
Interactive participation rate (%)	38.2	63.9	↑25.7 percentage points
Overall visitor satisfaction (1–5 scale)	3.92	4.46	↑0.54 points
Perceived knowledge gain score (1–5 scale)	3.75	4.38	↑0.63 points

As shown in Table 3, although the accessibility of sensitive areas has been "moderately tightened" in physical space, through digital means such as virtual restoration, multi-angle reconstruction, and task-based guided tours, the depth of explanations and the rates of reach and interaction participation have significantly increased. This indicates that tourists are no longer just "skimming through" but complete a more systematic viewing and understanding within the narrative that combines virtual and real elements. The improvement in satisfaction

and the acquisition of knowledge sense also suggest that the integration of virtual and real elements has not weakened the experience; instead, through the layered presentation of information and the meticulous organization of paths, the experience becomes more focused and memorable.

During actual operation, protection indicators (such as crowd density, stay time, contact events, and the number of environmental over-limit occurrences) and display indicators (such as interaction participation rate, satisfaction, and knowledge acquisition) continuously flow back to the data and service layer. On one hand, they are used to calibrate protection rules; on the other hand, they are also used to verify whether the virtual-real integration design truly achieves the dual goals of "high-quality display and low-risk carrying capacity". The comprehensive analysis of Table 2 and Table 3 shows that the virtual-real integration protection design proposed in this study not only significantly reduces the direct risks borne by the cultural relics themselves in terms of quantity, but also maintains or even improves the display effect through virtual substitution and interactive narration, laying the foundation for the subsequent construction of a data-driven tourism management model.

3.2 Comprehensive Benefit Analysis of the New Model of Tourism Management

Based on the implementation of the integrated virtual and real environment, this study further integrates the aforementioned data collection, rule encoding, and behavior evaluation capabilities into tourism management practices, forming a new management model of "time-based reservation + graded capacity control + behavior data-driven scheduling + virtual-real collaborative services". Compared with the previous management methods that relied on manual experience and static systems, this model demonstrates more significant comprehensive benefits in terms of passenger flow organization efficiency, tourist experience quality, and collaborative protection of cultural relics. This section conducts an analysis from the perspectives of management mechanism comparison and quantitative evaluation results.

Firstly, from the management mechanism perspective, the new model in the context of virtual-real integration no longer regards "ticketing - entry - visit - departure" as a linear process, but instead breaks down the entire process into several monitorable and adjustable management nodes: reservation and ticket checking at the entrance, flow and stay in key space units within the park, triggering and feedback of virtual content, rule triggering and capacity control intervention, etc. On this basis, through unified scheduling of the data and service layer, the practices of "post-event statistics" and "empirical judgment" in the traditional model are restructured, shifting management from "passive response" to "feedforward regulation". The key differences between the two models are shown in Table 4.

Table 4: Comparison between Traditional Management Model and the New Integrated Virtual-Reality Tourism Management Model.

Dimension	Traditional management model	Hybrid, data-driven virtual-physical management model	Overall assessment
Visitor flow organization	Mainly relies on manual judgment and experience; sudden congestion easily occurs at peak times	Based on real-time visitor flow monitoring and reservation data for time-sliced admission; local crowd limits are adjusted dynamically	Probability of congestion is significantly reduced, and queuing time becomes more controllable
Route design	Predominantly fixed routes with long adjustment cycles, making it difficult to optimize for different visitor segments	Recommended routes and hybrid virtual-physical scenarios are iteratively optimized according to behavior data from different time periods	Routes better match actual visiting habits, and spatial utilization becomes more balanced
Information services	Relies on static panels and face-to-face interpretation, with limited personalization	Uses apps, interactive screens and virtual tours to push differentiated content and task-based itineraries	Information reach is expanded, and learning paths become more diverse
Protection coordination	Protection requirements exist mainly as institutional rules, with enforcement depending on manual supervision	Protection rules are linked with environmental monitoring and behavior data; once thresholds are exceeded, interventions are triggered automatically	Protection measures are more timely and traceable, reducing blind spots in implementation
Decision support	Depends mainly on annual reports and fragmented statistics, with long feedback cycles	Uses evaluation models to generate multi-dimensional management scores, supporting rolling decisions and scheme comparison	Decisions are more data-informed, and the pace of adjustment is more flexible

As can be seen from Table 4, the new model does not simply add a "digital shell" on top of the existing system. Instead, it introduces measurable and traceable indicators at the key management links, enabling the trade-off among "flow - service - protection" to no longer remain at a purely theoretical level but can be simulated and selected based on specific data.

In terms of quantitative assessment, this paper selects the data from a certain period of the pilot operation, based on the management evaluation index system and comprehensive scoring model constructed in the previous part, to compare the overall performance of the traditional model and the virtual-real integration new model. To facilitate presentation, the indicators are divided into three categories: "operation efficiency sub-indicators", "tourist experience sub-indicators", and "protection coordination sub-indicators". The corresponding sub-scores and comprehensive scores are calculated, and the results are shown in Table 5 (all scores are normalized to 0-100).

Table 5: Quantitative Evaluation Results of Comprehensive Benefits of the New Tourism Management Model.

Indicator category	Representative indicators (examples)	Score of traditional management model
Operational efficiency sub-score	Average queuing time, peak crowding, spatial utilization balance, etc.	68.3
Visitor experience sub-score	Satisfaction, perceived knowledge gain, interactive participation, etc.	71.5
Protection synergy sub-score	Number of environmental exceedances, timeliness of rule triggering, risk events, etc.	65.8
Overall evaluation score	Weighted aggregation of the above indicator categories	68.9
Indicator category	Representative indicators (examples)	Score of traditional management model
Operational efficiency sub-score	Average queuing time, peak crowding, spatial utilization balance, etc.	68.3

As shown in Table 5, in terms of operational efficiency, the virtual-real integration new model effectively mitigates peak pressure in local areas through means such as time-based reservations, dynamic flow control, and route iteration, significantly alleviating the imbalance in queue time and space; in terms of visitor experience, through the combination of virtual and real explanations and task-based guided tours, the participation and learning satisfaction of visitors have significantly increased; in terms of protection collaboration, due to the linkage of protection rules with real-time monitoring and behavioral data, many problems that previously relied on manual inspections to be discovered can be detected and handled earlier, and the number and severity of risk events have been controlled. The improvement in the overall evaluation score indicates that the new model has achieved a relatively coordinated improvement among the three sub-indicators, rather than sacrificing one aspect to achieve improvement in another.

To further present the "structural differences" between the traditional management model and the new model in different dimensions, a comprehensive benefit analysis diagram can be constructed, visualizing and comparing the scores of the three dimensions of operational efficiency, experience quality, and protection collaboration. See Figure 3.

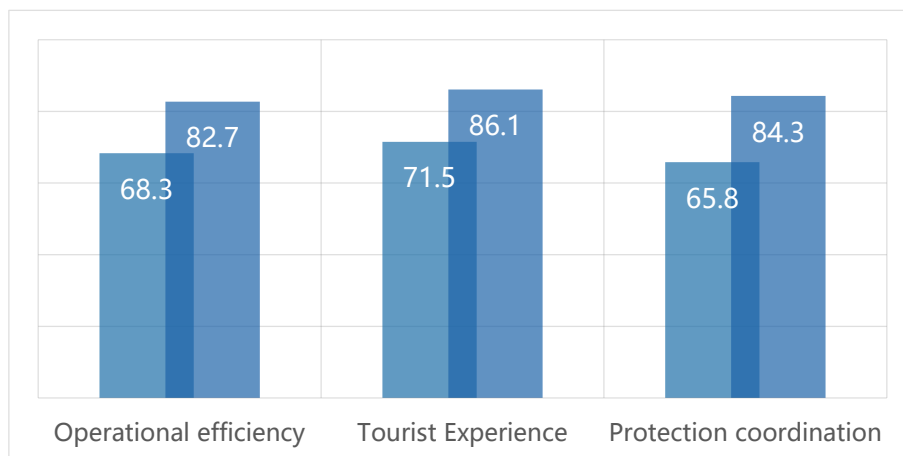


Figure 3: Diagram for Comprehensive Benefit Analysis of the New Tourism Management Model.

Figure 3 uses three key dimensions as the horizontal axes to compare the score distributions of the traditional model and the new model in each dimension. It can be seen that the new model maintains similar improvement rates in the "operational efficiency" and "tourist experience" dimensions, while the improvement rate in the "protection coordination" dimension is greater, presenting a structural characteristic of "protection first, efficiency and experience followed simultaneously". This structural improvement indicates that the virtual-real integrated management new model does not merely pursue "faster" or "more fun", but achieves a relative balance among multiple goals by data-driven fine-tuning and iteration under the premise of prioritizing protection goals.

Based on the analysis of Table 4, Table 5 and Figure 3, it can be concluded that the data-driven tourism management new model based on the virtual-real integrated display environment demonstrates relatively significant comprehensive benefits in the following three aspects: Firstly, in the operational efficiency aspect, through visualized passenger flow monitoring and reservation and limit-flow mechanisms, the order during peak periods becomes more controllable; Secondly, in the tourist experience aspect, through virtual-real narrative and interactive design, the content that is "understandable and memorable" has significantly increased; Thirdly, in the protection coordination aspect, through the linkage of rule engines and behavioral data, many potential problems that might accumulate into "major issues" are identified and intervened at the initial stage. These comprehensive benefits provide strong empirical support for the further promotion of the virtual-real integrated cultural heritage tourism management model on a larger scale.

4 Conclusion

This research systematically constructed and empirically analyzed the digital protection design of cultural heritage and the new tourism management model in the "virtual-real integration display environment", forming a relatively complete closed loop in three aspects: technical framework, protection mechanism, and management effectiveness. At the technical level, a three-layer architecture of "perception and collection layer - data and service layer - application and display layer" was proposed, along with an integrated scenario model of object - space - behavior - rules. The three-dimensional form of cultural heritage, environmental monitoring data, and tourist behavior data were uniformly encoded, providing a traceable and calculable data foundation for subsequent virtual-real integration protection design and management evaluation. At the protection design level, through the exhibition line organization of "remote viewing main line + virtual substitution", "space control of physical buffer + flexible isolation", and "linkage mechanism of monitoring warning + rule triggering", the peak flow density of sensitive areas was reduced from 3.2 people/square meter to 2.1 people/square meter, the average stay time was reduced from 165 seconds to 98 seconds, the number of incidents of close contact with cultural relics was reduced from 5.3 times/day to 1.2 times/day, and the number of times the environmental indicators exceeded the standard was reduced from 12 times/month to 4 times. This indicates that without significantly reducing the viewing opportunities, the layered virtual-real display effectively "smoothed the peaks and filled the valleys", significantly reducing the instantaneous pressure on the cultural relic itself and the environmental carrying capacity. At the display and management level, through virtual restoration, multi-angle reconstruction, and task-based guided tours, the reach rate of in-depth explanations increased from 46.8% to 71.5%, the interactive participation rate increased from 38.2% to 63.9%, and the overall satisfaction and knowledge gain scores of tourists increased by 0.54 points and 0.63 points respectively. Based on the evaluation model calculation, the sub-score of operational efficiency and the sub-score of tourist experience increased from 68.3 and

71.5 to 82.7 and 86.1 respectively, the sub-score of protection coordination increased from 65.8 to 84.3, and the comprehensive management score increased from 68.9 to 84.8, indicating that the new model is not "exchanging experience for safety" or "pressuring protection through efficiency", but achieving a coordinated rise in safety, efficiency and experience under the constraint of prioritizing cultural relic safety. From a methodological perspective, this research proves that integrating three-dimensional digitalization, environmental monitoring, tourist behavior and rule engine into the same platform and conducting closed-loop evaluation through multi-dimensional indicators and comprehensive scoring models is a feasible path to promote cultural heritage protection from "static display" to "data-driven governance".

About the Author



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