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Key Technology of Virtual Roaming System in the Museum of Ancient High-Imitative Calligraphy and Paintings

JING LI AND NING YU
College of Art, Qingdao Agricultural University, Qingdao 266109, China
Corresponding author: Ning Yu (yuningluck@126.com)

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ABSTRACT To show the traditional Chinese painting and the spiritual culture of universities, highlight the artistic accumulation and cultural heritage, analyze the value and significance of digitalizing the Museum of Ancient High-Imitative Calligraphy and Painting, Qingdao Agricultural University (QAU) is regarded as the research object. The design principles of the digital museum are clarified by understanding the specific user needs, and the 3DS Max is utilized to develop a roaming system for the Museum of Ancient High-Imitative Calligraphy and Painting of QAU through Unity3d, a Virtual Reality (VR) software platform. Besides, the perspective control, collision detection of virtual characters and scenes, and control of pop-up information display windows are realized to achieve the interactive design of users and the QAU digital museum system. Finally, from the four aspects of resource content, information presentation, resource presentation, and learning effect, a comprehensive evaluation is conducted. The research results show that more than 80% of people think that the content satisfaction of virtual system resources is high, which is more scientific and accurate; more than 65% think that the information is presented better, and 87% think that the system is open enough; in addition, nearly one-third of the visitors believe that using the system can initiate their interest and motivation in learning. This shows that the learning and cultural communication effects of the virtual system are more obvious. This system realizes the objective of disseminating traditional classic art culture and values by new technical means, which has reference significance for research in other fields.

INDEX TERMS Virtual roaming, high-imitative calligraphy and painting, digital museum, digital system.

I. INTRODUCTION

Museums are carriers for disseminating, preserving, and displaying historical and cultural knowledge, science, technology, and social features to the public. With the development of China's culture and education, museums have been valued by more people [1]. The major function of museums is to spread the scientific and technological concepts, cultural connotations, and true meaning of life to the visitor through entertainment and art [2]. The digital museum can drive visitors to learn and experience digital history and culture through multimedia forms, such as pictures and videos [3]. Research on digital museums started in the United States. With the continuous development and popularization of computer technology [4], [5], US scientists incorporated the collection information into the network database system to make the collection information break through the limitations of physical museums [6]. Olesen (2016) found that countries are strengthening the application of computers in the field of museums, and have begun to use digital virtual technology to protect their cultural heritage [7]. How to better embody the museums' functions of display, education, and research, better serve the society and the public, and promote the development of the museums is a more prominent problem currently [8]. As the network information technology develops rapidly, the virtual digital museums built by network technology and Virtual Reality (VR) technology widen the extension space and maximize the function of the museums, forming a fast, comprehensive, and effective way of visiting museums [9]. Therefore, studying digital museums is of great significance for the public to understand history and culture.

The digital museum is a virtual museum that is presented on the Internet in three-dimensional form based on three-dimensional imaging technology, interactive manipulation

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technology, VR technology, and special effect production technology [10]. Specifically, it uses the Internet and the internal information architecture system of the institution to display the business work of traditional museums in a computer virtual network; by closely integrating the two, the museum is presented to the public in a virtual form; such a virtual form uses a lively three-dimensional model to replaces the original boring plane data so that the function of the physical museum can be fully realized [11]. Pu and Zhao (2018) found that when choosing which cultural heritage resources to display, the museum needs to consider not only the resources available to the museum itself but also the intensity of the user's demand for specific information [12]. China began the research, exploration, and construction of virtual museums in the early 1990s. Due to the strong support of government departments in policies, coupled with strong social needs, a good start has been created for the development of virtual museums in China. The digitalization of museums has become more mature and standardized both technically and theoretically [13]. As a place to collect, protect, and display various important exhibits, university museums are an important part of the cultural infrastructure of colleges and universities, and an important education base for implementing quality education and improving the cultural quality of students [14]. The continuous development of computer technology has promoted the development of virtual reality technology and made it possible to digitalize the QAU Museum of Ancient High-Imitative Calligraphy and Painting. The digital museum can provide users with sufficient convenience and has attracted increasingly more attention from users.

By clarifying the design principles of the digital museum and understanding the specific user needs, the 3DS Max is utilized to develop a roaming system for the Museum of Ancient High-Imitative Calligraphy and Painting of Qingdao Agricultural University (QAU) through Unity3d, a Virtual Reality (VR) software platform. This will play a positive role in the protection of the works and the promotion of the Museum of Ancient High-Imitative Calligraphy and Painting of QAU. Here, the VR technology is applied to the field of museum digitalization for the first time, which is a bold attempt of new technology in the fields of art and culture. Through the digital design of the Museum of Ancient High-Imitative Calligraphy and Painting of QAU, the physical museum building and display will be reconstructed with digital technology, which will greatly facilitate the user's visit, as well as the reproduction, protection, and promotion of cultural relics.

II. METHODS

A. 3D SCENE-MODELING TECHNOLOGY

In the process of designing and implementing the VR system, the virtual environment must be designed and constructed in detail. Therefore, the modeling and construction of a 3D scene has a huge influence on the implementation of the entire virtual reality system. Only through 3D scene modeling can operations such as real-time rendering, texture mapping, lighting processing, interaction, and real-time roaming be performed on the system, thereby making the virtual world built more realistic. The current 3D scene modeling technology is mostly based on the following technologies: (1) geometry-based modeling technology; (2) image-based modeling technology; (3) geometric and image-based hybrid modeling technology.

The objective is to show the content and characteristics of ancient high-imitative calligraphy and painting. Image-based modeling technology has a small amount of calculation and a fast modeling process. At the same time, it does not require high computer configuration. Users can easily realize the implementation of complex scene modeling through their computers. This technology uses external equipment to shoot the scene in real-time and the computers to process and splice the image information in the scene; therefore, the scene can be presented to the users more realistically, meeting the requirements of different users to observe and operate the scene from multiple angles. The modeling method based on image rendering can quickly collect scene data during the modeling process, as well as realistically reflecting the object characteristics in the scene. In addition, it can solve the problems encountered in the process of digital museum scene modeling, such as user interaction with virtual objects and the lack of immersion in the scene.

Therefore, in the virtual modeling process of the museum scene, the hybrid modeling method is adopted. The panoramic modeling of the scene is carried out through image processing technology, and the image information is collected from multiple angles and sent to the computer for processing, thereby producing a more realistic visual experience of the model. Besides, the geometry-based modeling methods are utilized to design interactions between users and museum collection models, achieving a better display effect of the QAU museum. The hybrid modeling technology is shown in Fig. 1:

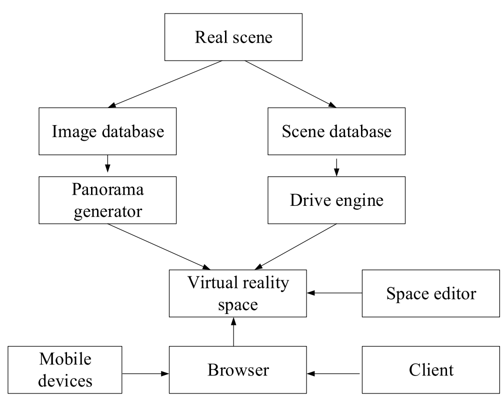

FIGURE 1. Process of hybrid modeling technology.

B. 3D SCENE-ROAMING TECHNOLOGY

The 3D roaming system presents not only a real space but also a real simulated virtual space of an imaginary space, which is a virtual environment within a specific range. The virtual environment has the characteristics of real integration of viewing, listening, and touching. The roaming users are in the virtual space in a natural way. In this space, the users must use the necessary equipment to observe in all directions. The virtual objects in the environment not only can make users feel immersive but also can be planned and operated. Roaming scenes are mainly divided into indoor scene management and outdoor scene planning.

(1) Indoor scene management based on Binary Space Partitioning (BSP) tree:

Technically, BSP utilizes walls or glass to divide the space. These walls or glass are orthogonal or approximately orthogonal in the building body; in this way, the objects in the space can be gradually separated according to the pre-defined walls or glass. Then, these separated objects are separated again into other independent spaces, which can be rendered independently. Therefore, a subspace organized by the BSP tree is formed. This subspace is formed through such a static preprocessing technology, and the subspace that needs to be rendered is rendered through the real-time rendering technology. This improves the efficiency of real-time rendering, during which the system only needs to render the dynamic parts. The specific algorithm flowchart is shown in Fig. 2:

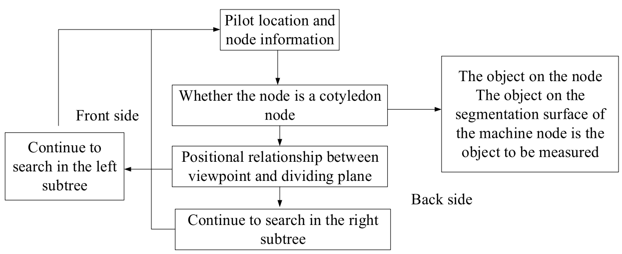

FIGURE 2. **Algorithm structure of indoor scene management based on BSP tree.**

(2) Image-based outdoor virtual roaming technology:

The basic data of image-based virtual roaming technology come from the process of collecting information. Some of the data come from discrete images collected by cameras, and some from continuous images collected by cameras. These information data are processed through image processing to obtain the panoramic images. Then, the obtained panoramic images are organized into a virtual reality space. During this organization process, a suitable space model is chosen. In this virtual reality space, users can operate the scene in different directions, which realizes 3D scene roaming from all aspects.

A panoramic image generator and a space editor are utilized to generate a virtual reality space. The panoramic image generator is mainly responsible for stitching ordinary images or videos into panoramic images. These ordinary images have overlapping parts, and the video is continuous. The space editor organizes many panoramic images into a virtual real space, and the image processing includes perspective transformation, flattening, compositing, and cropping methods.

C. OVERALL DESIGN OF THE DIGITAL MUSEUM

User demand and system positioning of digital museum system: the goal of analyzing the user needs of the digital museum system and the positioning of the system design is to meet the needs of visitors and thus generate practical values [15]–[19]. The system design is to reproduce the Museum of Ancient High-Imitative Calligraphy and Painting of QAU building as realistically as possible so that users can have the same experience of visiting the physical museum through the system. To achieve this goal, in terms of the system content, it is necessary to fully utilize various forms of media such as images, sounds, and videos, which is of great historical and aesthetic value to the comprehensively describe the buildings of the Museum of Ancient High-Imitative Calligraphy and Painting of QAU. First, by observing and comparing the topographic structure and model characteristics of the project, a 3D laser scanner is utilized to obtain cloud data in the school museum, as well as taking photos of details such as doors, windows, stairs, and booths. The obtained cloud data are imported into 3D Max to create a 3D model with the photos. Then, the model is imported into the VR-Platform to make virtual scenes and interactive functions. Finally, the model is saved as an exe file and exported. The entire virtual roaming system is completed.

(1) Design principles: the first is optimization. To ensure the operating efficiency of the system while not losing the quality of the image as much as possible, two processing methods are adopted. One method is to use textures instead of modeling with subtle parts to reduce the data volume of the model while ensuring that the model will not lose the image quality, that is, using textures to supplement the lack of detail caused by the model; as for the other method, by splitting a model into multiple models and selecting different scenes to choose to load different models, the data amount of a single model can be as low as possible. In addition, in the process of modeling, it is also necessary to try to reduce the number of faces and vertices of the model, as well as reducing the calculation of computer rendering during the later roaming process. The second is intuition. When visitors from different regions and even different countries are experiencing the digital museum, they will inevitably encounter cultural differences in understanding the exhibits through the senses such as vision and hearing. How to enable visitors in different regions to better understand the culture and spirit contained in the Museum of Ancient High-Imitative Calligraphy and Painting of QAU requires the principle of intuitiveness in the digital design process of the museum, that is, not only the language and characters but also the multimedia methods such as graphics, images, and sound are used in the display of the digital museum so that people from all walks of life in different regions, cultures, and ethnic groups can better enjoy and learn about the art and culture of the Museum of Ancient High-Imitative Calligraphy and Painting of QAU.

(2) Overall process: before the digital model of the Museum of Ancient High-Imitative Calligraphy and Painting

of QAU and surrounding scenes are formally produced, it is necessary to collect information about the relevant physical museum and surrounding scenes. The museum can be modeled through the architectural design drawings of the building and assisted with on-site building photos. For the surrounding scenes, on the one hand, photos of the scene environment are taken; on the other hand, the size of the surrounding scenes can be referred to the size of the museum building. The overall process is shown in Fig. 3:

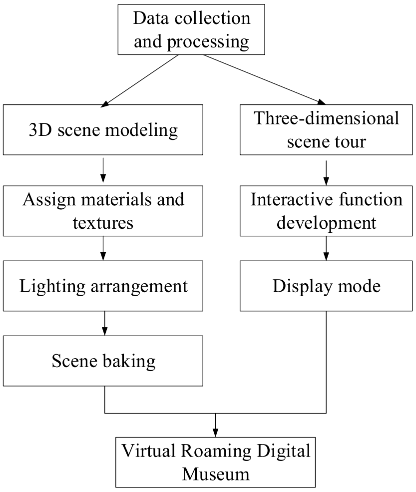

FIGURE 3. Virtual roaming design process for the Museum of Ancient High-Imitative Calligraphy and Painting of QAU.

D. IMAGE COLLECTION AND PROCESSING

(1) Image collection: it mainly utilizes the image scanning method. The approximate location of the scanner site is set according to the internal structure of the museum, and the scanning is started under the premise of minimizing occlusion. To facilitate the later point registration, it should be noted that a 10%-20% overlap should be set between the scanned data of each two stations. The scanned data can be used in 3D Max after a series of processing such as registration, impurity removal, and format conversion through software. Then, the internal structure of the museum is observed. According to the needs of model material and texture, detailed photos of the internal structure are taken with a camera and processed with Photoshop software.

(2) Image processing: the method of wavelet transform operator is utilized. If the image p has different pixels, p is decomposed at a certain scale, and the appropriate 2D smoothing function $\theta(x, y)$ is selected; then, the function will be defined as:

$$\psi^1(x, y) = \frac{\partial\theta(x, y)}{\partial x} \tag{1}$$

$$\psi^2(x, y) = \frac{\partial\theta(x, y)}{\partial x} \tag{2}$$

By constructing a discrete filter, the discrete binary wavelet transform of each point is calculated on different scales, where the modulus of the point *(m, n)* is calculated as:

$$M_2^{\mathrm{d}} f(m, n) = \sqrt{\left|W_{2d}^1 f(m, n)\right|^2 + \left|W_2^2 \mathrm{j}^d f(m, n)\right|^2} \tag{3}$$

Then, the phase angle should be:

$$A_2^{\mathrm{d}} f(m, n) = \arctan \frac{W_2^2 \mathrm{j}^d f(m, n)}{W_2^1 df(m, n)} \tag{4}$$

where $W_{2\,j}^{2\ d} f(m, n)$ is the discrete binary wavelet transform value of point 2, and $W_{2\,j}^{1\ d} f(m, n)$ is the discrete binary wavelet transform value of point 1.

Second, due to the differences between different images, image registration technology is also utilized. Image registration finds the conversion relationship in multiple images. These images must be in the same area, mainly in the same scene. Then they are matched. The image is defined as follows: I_1 and I_2 are used to represent the reference image and the image to be registered, respectively; thus, the registration relationship between the two images is as follows:

$$I_2(x, y) = g(I_1(f(x, y))) \tag{5}$$

In (5), f and g represent the 2D geometric transformation function and the one-dimensional gray-scale transformation function, $I_2(x, y)$ and $I_1(x, y)$ represent the gray value of the reference image and the image to be registered at the point (x, y), respectively. Normally, g does not need to be calculated; thus, the task of image registration is to obtain the optimal f. Hence, the above equation can be simplified into:

$$I_2(x, y) = I_1(f(x, y)) \tag{6}$$

To detect the details of images, the Haar classifier is utilized. This is a traditional image processing algorithm based on machine learning, which mainly relies on the rotation of the image to obtain the feature values of different images. This type of algorithm is characterized by fast detection and slow training. The specific calculation process is as follows:

First, the image is filtered and detected. The filtering is completed according to the difference operators in the vertical and horizontal directions, and the respective derivatives I_x and I_y of the pixels are calculated in the two vertical directions, thereby obtaining the following matrix:

$$m = \begin{bmatrix} I_x^2 I_x I_y \\ I_x I_y I_y^2 \end{bmatrix} \tag{7}$$

After the Gaussian filtering of the above matrix m is passed, the Gaussian function of autocorrelation function matrix M is:

$$w = \exp(-\frac{x^2 - y^2}{2\pi\sigma^2}) \tag{8}$$

Then, the matrix M could be expressed as:

$$M = m \otimes w = \begin{bmatrix} I_x^2 I_x I_y \\ I_x I_y I_y^2 \end{bmatrix} \otimes \exp(-\frac{x^2 - y^2}{2\pi\sigma^2}) \tag{9}$$

The above calculation obtains the Harris corner detection operator R for each pixel, where:

$$R = \det(M) - KTr^2(M) \tag{10}$$

When the operator R is greater than some threshold, the corner point is regarded as a point that obtains a local extreme value in some field. Here, R = 0.3 and K is a constant.

E. IMPLEMENTATION OF DIGITAL MUSEUM VIRTUAL SYSTEM

(1) Model scene implementation: the 3D Max software is used for design and production. Before making the building model of the QAU Museum of Ancient High-Imitative Calligraphy and Painting, first, the corresponding scene construction method is selected according to the shape and structural characteristics of the building. The system adopts the hybrid scene construction method. This method first establishes the bottom surface of the building model; then, through the modification toll in the extrusion tool kit, the plane is made into a 3D building, and the roof is made by referring to the building. In the entire building modeling process, CAD drawings must first be imported into 3D Max, which are utilized as the background view of the entire view window. By using the drawings as the dimension basis, the outer contour of the Museum of Ancient High-Imitative Calligraphy and Painting of QAU building is formed by drawing lines. Based on the outer contour, through the modification toll in the extrusion tool kit, the 2D line contour is extruded into a 3D geometry, which is the model of the Museum of Ancient High-Imitative Calligraphy and Painting of QAU building. In the process of extrusion, the height of the building is considered, which should be above the height of the two floors plus the height of the ground and roof. The roof is constructed by the method of patch modeling, and the external facade on the side of the building is constructed by adding planes. The detail model is shown in Fig. 4:

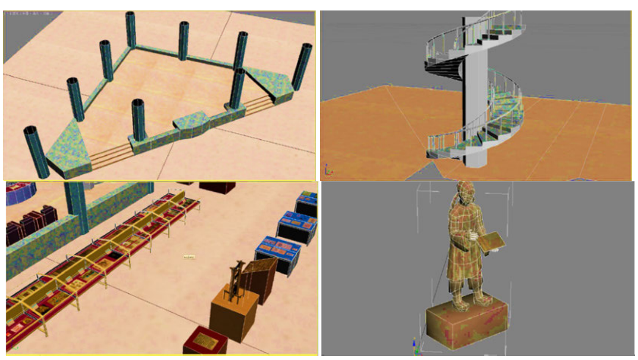

FIGURE 4. Reproduction of the building detail model of QAU Museum of Ancient High-Imitative Calligraphy and Painting.

(2) Assigning materials and textures: after the scene is created, it can be assigned with materials. The final model should be imported into the VRP editor to build the virtual roaming system. VRP only supports standard materials; therefore, advanced materials such as Vray and Mental Vray should be avoided when modeling. After the model material is assigned, the ''UVW'' map should be added to facilitate the adjustment of the material in the VRP. It should be noted that to optimize the effect, fine photos of details should be taken, such as stair handrails, marble steps, wooden doors, and windows; also, the Photoshop software is utilized for editing and color toning. After all textures are created, the 3D Max model needs to be exported in.obj format, and the exported model is imported into Deep Paint 3D to prepare for the subsequent mapping of the entire building. Deep Paint 3D is a model mapping tool, which maps the plan to the surface of the 3D model. Multiple layers are created in Deep Paint 3D software. The textures are mapped from multiple angles to the museum building model one by one. Finally, the mapped models are imported into 3D Max software. The texture production process is shown in Fig. 5:

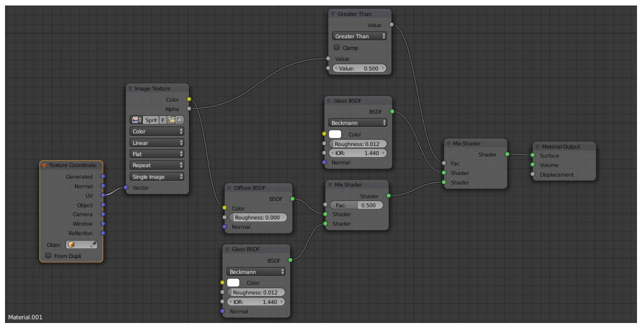

FIGURE 5. Process of texture production.

(3) Lighting arrangement: light is set, and a free spotlight is established. The spotlight parameter is set to 40, and the attenuation parameter is set to 60. The spotlight is copied to the top of the showcase for lighting according to the layout of the venue. Floodlights are established to fill the dark parts of the scene. 3D Max has its lights and supports Vray lights. VRP also supports these two lights. The Vray renderer has excellent performance and effects; thus, the Vray renderer is recommended. When arranging the lights, the light sources should be minimized. Too many light sources will increase the system overhead. When adding the light sources, the order of the main light source and then the auxiliary light source should be followed. In addition to making the model more realistic, the lights should also bring out the lighting effect of the spotlight. Therefore, parameters such as ''multiplier'' and ''sampling range'' in the shadow map of the light should be set carefully. After the rendering is finished, the lights are adjusted to obtain the required effects. The adjustment process is shown in Fig. 6.

(4) Scene baking: the goal of baking is optimization. Baking light maps will produce lighting and shadow effects to create fake lighting. When lighting effects are not considered, baking light maps is unnecessary. Using only textures to express the effects will reduce the amount of calculations that files are imported into the engine, which can make the project more efficient. Since the model built in 3D Max needs to be imported into VRP, the following points when baking should be valued: VRP only supports the textures of the two baking methods of Complete Map and Lighting Map; the default

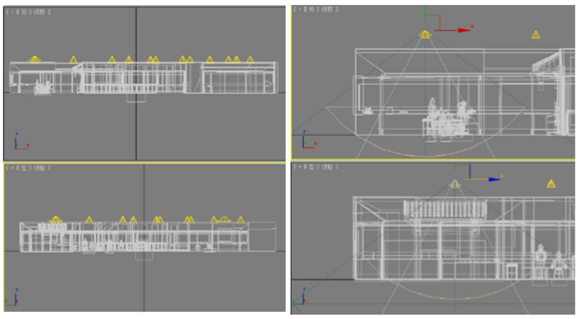

FIGURE 6. Process of light adjustment.

texture of baking is 256∗256, but large-sized objects should be resized; the baked texture cannot have the same name. The model after scene baking is shown in Fig. 7.

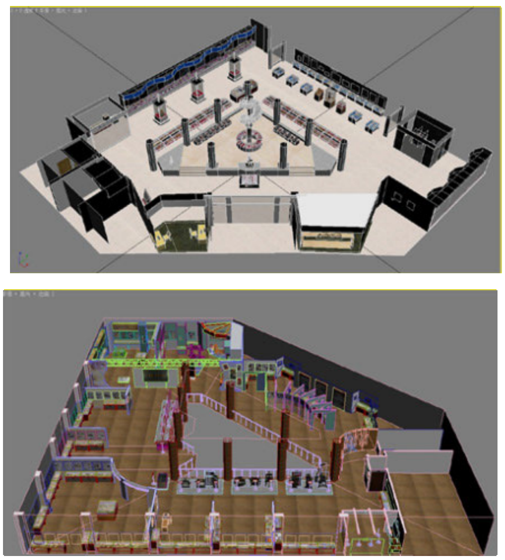

FIGURE 7. Scene baking renderings.

F. PATH PLANNING PROBLEMS IN VIRTUAL ROAMING

Of late years, there have been great breakthroughs in path planning, mainly in the fields of robots, unmanned aerial vehicles (UAVs), and virtual reality. While solving the path planning problems, the path-finding algorithm is gradually updated, and new algorithms with better performance appear one after another. Under different scenarios, the performance of the path-finding algorithm is different, and various application scenarios also put forward higher requirements for the efficiency and storage space of the path-finding algorithms.

Ant Colony Optimization (ACO) algorithm is a newly developed bionic optimization algorithm that simulates the group behaviors of ants in nature foraging. The ACO algorithm uses a positive feedback mechanism to converge the searching process continuously, and finally, gradually approach the optimal solution. Meanwhile, each individual can affect the surrounding environment by releasing pheromone, as well as perceiving the real-time changes in the surrounding environment. Besides, ACO algorithm is a heuristic search, which is not easy to fall into the local optimum. In nature, ants will choose the route with the highest pheromone concentration and continue to release pheromone during the journey so that the pheromone concentration on this path always remains the highest.

The ACO algorithm takes a long time during searching; after the algorithm searches to some extent, all ants will choose the same path, which is not conducive for the algorithm to further search the solution space. Therefore, the algorithm will fall into the local optimum prematurely; in other words, premature phenomenon occurs. Hence the traditional ACO algorithm is improved before being applied to the path planning of the virtual roaming system, which will improve the performance of the algorithm and make the system more efficient and reliable.

Because the chaotic optimization has the characteristics of using the chaotic sequence to traverse all the states in some range without repetitively traversing, it has obtained superior performance than the random sequence. Therefore, the chaotic optimization theory is adopted to improve the ACO algorithm. The improvement ideas are: (1) using the advantages of the faster search speed of the turbidity optimization to generate a set of better solutions to solve the problem of lacking initial pheromone houses in the ant colony algorithm; (2) using the chaotic disturbance to jump out of the local optimal solution and introducing it into the ACO algorithm to enhance the later search ability of the algorithm.

Based on the Max-Min Ant System (MMAS) theory, the pheromone is disturbed by the idea of secondary carrier in chaotic optimization, which makes the algorithm stronger and enables the algorithm with the ability to jump out of the local optimal solution. The improved Chaos MMAS (CMMAS) algorithm uses the branch influence factor λ to determine whether it is stuck, which is a quantity related to the search space dimension. The branching factor λ_i is defined as the number of subsequent edges where node i meets the condition. The specific definition process is as follows:

$$\tau_{i,j} > \lambda_i \delta_i + \tau_{j,\min} \tag{11}$$

$$\delta_i = \tau_{j,\max} - \tau_{j,\min} \tag{12}$$

$$\tau_{j,\max} = \max_{j \in N_i} \left\{ \tau_{i,j} \right\} \tag{13}$$

$$\tau_{j,\min} = \min_{j \in N_i} \left\{ \tau_{i,j} \right\} \tag{14}$$

$$\tau_{i,j}(t) = \begin{cases} \frac{1}{G^k(t)}, \text{ optimal path } [i, j] \\ 0, \textit{ others} \end{cases} \tag{15}$$

where i and j are two points forming an edge, N_i represents the set of all nodes connected to node i, $\tau_{i,j}$ is the value obtained from the pheromone update operation, and $G^k(t)$ is the path length of the current elite ants, that is, the global optimal path length.

The chaotic method is utilized to perturb the pheromone, and the following equations are obtained:

$$\tau_{i,j}^{c} = \frac{\tau_{i,j} - \tau_{\min}}{\tau_{\max} - \tau_{\min}} \quad (16)$$

$$\tau_{i,j}^{c}(t+1) = \rho\tau_{i,j}^{c}(t) + r * (2c - 1) \quad (17)$$

In (16) and (17), ρ represents the retention rate of pheromone, $\tau_{\max}$ is the maximum value of pheromone, $\tau_{\min}$ is the minimum value of pheromone, r is the chaotic disturbance radius, and c is the chaotic factor generated by Tent mapping.

G. IMPLEMENTATION OF DIGITAL MUSEUM ROAMING SYSTEM

(1) The development of interactive functions: it is controlled by the script engine in the Unity3D virtual roaming engine. The biggest advantage of Unity 3D is the cross-platform nature of the scripting language. In the past, software often did not have such characteristics. The compiled program can only run on a single platform, which is very inconvenient. In Unity 3D, most of the platform-related code is placed inside the game engine so that the code related to the game content can be executed across platforms, which is convenient and fast, and saves a lot of manpower and material resources. Before digitizing the interactive design of the Museum of Ancient High-Imitative Calligraphy and Painting of QAU system, the preparatory work that needs to be done is to import the intermediate conversion data format FBX file generated in the early stage into the newly created project file in Unity 3D. Because the objects in the scene must have basic collision detection functions, the size of each model and the option to accept collision must be checked before creating the scene. After adjusting the position of each model, it is necessary to create the material of the model. The development process of Unity 3D is shown in Fig. 8:

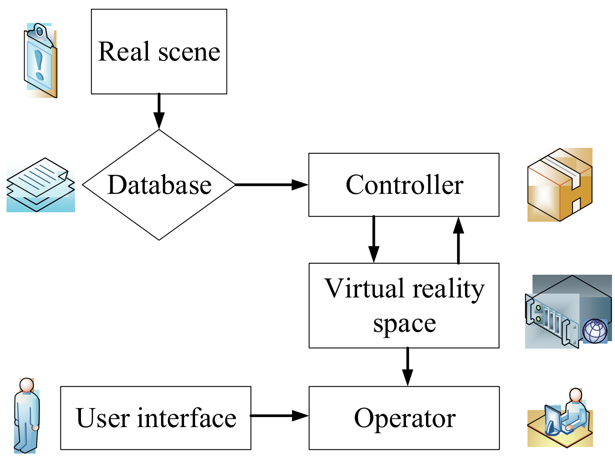

FIGURE 8. Function implementation of Unity 3D.

(2) Roaming system: there are two major roaming modes in VRP, the fixed roaming and autonomous roaming. The fixed roaming is simple; the autonomous roaming is highly free and has many viewing angles, whose user experience is more sufficient. Walking along a fixed route in skeletal animation is the basis of multiple fixed roaming effects, and multiple cameras should be attached to it. This system realizes the roaming of the scene in two ways through the character tracking camera, walking camera and character control camera. When using the role tracking camera for third-person perspective roaming, the selection between the two modes, "movement control" and "fixed-point viewing", should be noted. Movement control mode means that the camera moves with the character; while in the fixed-point viewing mode, the camera is fixed, only the character is moving, and the viewing angle distance will vary with the character's movement. In autonomous roaming, the "far clipping plane" and "near clipping plane" in the properties of the walking camera can define the clipping distance in the camera perspective. The system will use the default value, or the value can be customized according to the needs of the scene. It should be noted that when the "walking" mode is selected, the system will automatically turn on the collision detection of the camera. In the flight mode, users can choose whether to detect the collision according to their needs. In the "Character Control" camera, users can double-click the camera, choose to track the created character model, and adjust the parameters. After all the parameters are set, users can perform simple autonomous roaming through W (forward) S (backward) A (left shift) D (right shift) keys on the keyboard, as shown in Fig. 9.

FIGURE 9. Schematic diagram of roaming system implementation.

(3) System display mode: for the Windows version of the digital roaming system of the Museum of Ancient High-Imitative Calligraphy and Painting of QAU, the final product system is an.exe file that can be run directly. It can run directly in the Windows system environment

by double-clicking. Control commands are input through commonly used user command input interfaces (keyboard and mouse), and the corresponding movement is generated through the system's recognition of the commands. The default keyboard control mode of the digital museum roaming system is to control the forward, backward, left, and right movement of the viewing angle in the system through the WSAD key of the keyboard; the left and right keys of the mouse are used to control the left and right rotation of the viewing angle in the system.

H. EVALUATION OF DIGITAL MUSEUM SYSTEM EFFECTS

To comprehensively evaluate the effectiveness of the digital museum system, the overall indicator evaluation system of Likert scale is adopted. From the dimensions of "resource content, information presentation, resource presentation, and learning effect", a questionnaire survey is performed. The personnel of QAU museum fill in the questionnaire immediately after they use the system. The questions are designed according to relevant literature, and the reliability and validity of the questionnaire data are tested.

(1) Reliability analysis: the Cronbach's alpha coefficient method proposed by Hadjichambis *et al.* (2020) is utilized [20]. When the coefficient is between 0.7-0.8, it means that the questionnaire results have a high degree of credibility; when the coefficient is between 0.65-0.7, the reliability is within the acceptable range, when the coefficient is between 0.6-0.7, the questionnaire survey results are not credible [21].

(2) Validity analysis: Ratio Statistic Test (RST) method is used for validity analysis, which is judged by redundancy and sensitivity. The Redundancy Degree (RD) represents the independence and redundancy of each indicator. When RD is ≤ 0.5, it means the indicator is valid. The smaller the RD value is, the higher the validity is. The Sensitivity Degree (SD) represents the adaptability of different evaluation systems on evaluation indicators. When SD is ≤ 5, the indicator is valid [22].

(3) The questionnaire is designed according to the three-level indicators in the performance evaluation. Each question has 5 options: "very non-conforming", "relatively non-conforming", "general", "relatively conforming", and "very conforming", corresponding to 1, 0.8, 0.6, 0.4, and 0.2 points. A total of 300 questionnaires have been issued, and 292 questionnaires have been recovered, in which 280 copies are valid. The recovery rate is 97%, and the valid rate is 97%. Among them, A1, A2, A3, A4, and A5 are very inconsistent, relatively inconsistent, general, relatively consistent, and very consistent.

(4) Normalization processing: before modeling, all the data are normalized first. The calculation method utilized is as follows: all results are averagely weighted to calculate the final score of each indicator, and the normalized interval is [0, 1]. The specific equation is as follows:

$$X = \frac{x - x_{\min}}{x_{max} - x_{\min}} \tag{18}$$

To reduce the error effectively, all the matrices are tested for consistency. The specific calculation is as follows:

$$CI = (\lambda_{\max} - n) / (n - 1) \tag{19}$$

In (19), $\lambda_{\max}$ is the maximum eigenvalue, which is the average value of Aw_i/w_i; w_i is the component vector of each row of the matrix multiplied by the weight W and summed; Aw_i/w_i is the divisor of the matrix and its corresponding component vector; N is the number of data. Also, the average random consistency index RI is utilized to determine the approximate range of inconsistency. The consistency ratio CR (CR = CI/RI) is adopted to determine whether the matrix is consistent (if CR is < 0.1, the judgment matrix will be consistent).

III. RESULTS

A. ALGORITHM PERFORMANCE OF VIRTUAL ROAMING PATH PLANNING

In the ACO algorithm, the parameter is utilized to adjust the influence of the remaining pheromone on the path on the next ant colony search, which controls the convergence speed of the algorithm. To verify the influence of the parameters on the algorithm, test cases KroAlOO, d198, eil51 and lin318 of the standard traveling salesman problem (TSP) are utilized for testing. The value of ρ starts from 0.1, and a value is taken every 0.1 for verification. Finally, a set of $\rho = 0.95$ experimental groups is added. Figures 10-13 show the experimental results with ρ values ranging from 0.5 to 0.95.

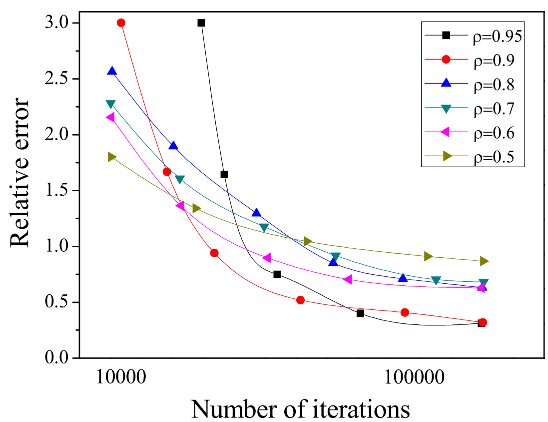

FIGURE 10. KroAlOO experiment results of different ρ.

When the number of iterations is small, a smaller value of ρ can be selected to obtain a better solution. However, this does not converge faster in the true sense; instead, it prematurely converges toward the local optimal solution. When the value of ρ is large, the algorithm does not have an advantage when the number of iterations is small; as the number of iterations increases, the algorithm obtains a stronger spatial search ability, and finally, obtains a better search result.

Next, the four standard test datasets of KroAlOO, d198, eil51 and lin318 are utilized to evaluate the performance of the ACO algorithm fused with chaotic optimization, which is compared with the Ant Colony System (ACS) algorithm

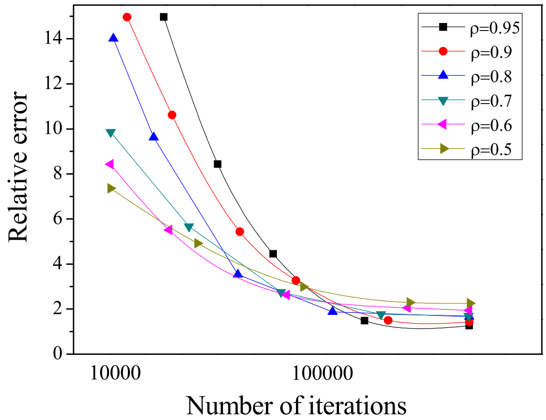

FIGURE 11. d198 experiment results of different ρ.

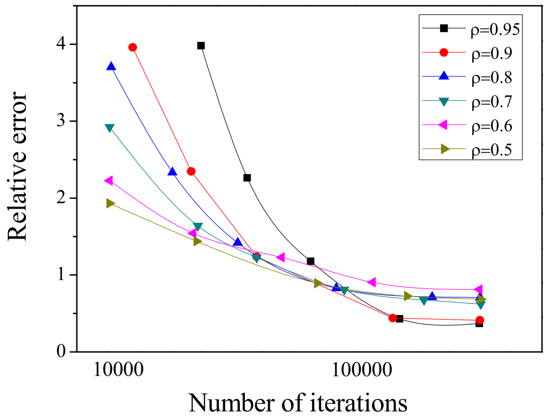

FIGURE 12. eil51 experiment results of different ρ.

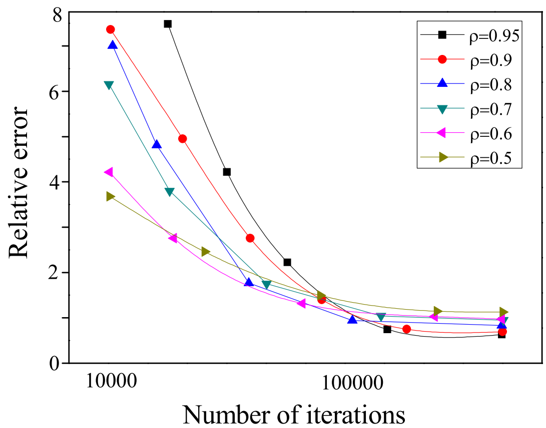

FIGURE 13. lin318 experiment results of different ρ.

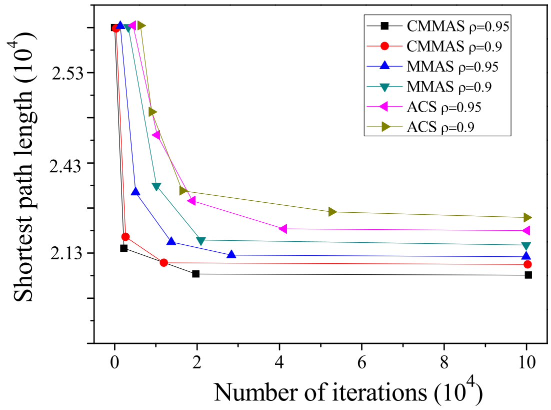

FIGURE 14. The iterative convergence curves of different algorithms in KroAlOO.

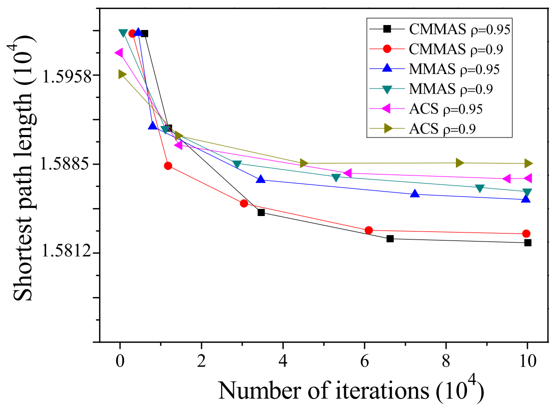

FIGURE 15. The iterative convergence curves of different algorithms in d198.

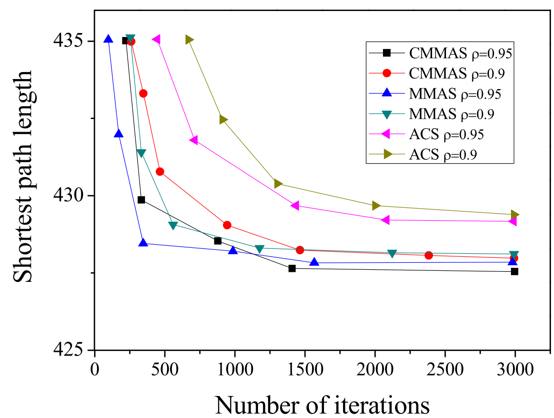

FIGURE 16. The iterative convergence curves of different algorithms in eil51.

and the MMAS algorithm. The comparison results are shown in Fig. 14-17.

For the small-scale TSP problem eil51 dataset, the optimization efficiency of CMMAS and MMAS is not much different, and both are significantly better than the traditional ACS algorithm; at this moment, compared with the MMAS algorithm, the improved algorithm does not show its superiority. For the KroAlOO and d198 datasets, CMMAS not only has an advantage in convergence speed but is also superior to MMAS in terms of solution quality. When CMMAS is tested in the lin318 dataset, although the convergence speed in the early stage is slightly slower than MMAS, it shows a good ability in jumping out of the local optimal solution in the later stage of the search, and finally, obtains better solution accuracy.

B. DATA INSPECTION OF QUESTIONNAIRE SURVEY

The ''Analysis/Measurement/Reliability'' of the IBM SPSS Statistics 22 software is utilized to analyze the reliability of the five dimensions included in the questionnaire separately. The obtained alpha coefficient values are all greater than 0.8,

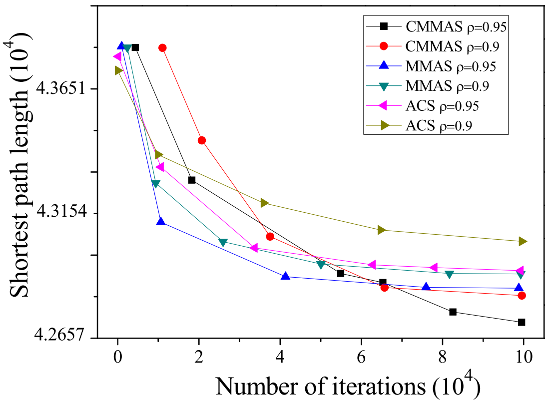

FIGURE 17. The iterative convergence curves of different algorithms in lin318.

TABLE 1. Reliability test of virtual roaming system evaluation system.

	Cronbach's alpha	alpha coefficient
Resource content saturation	0.86	0.96
Information presentation saturation	0.85	0.97
Resource presentation saturation	0.80	0.96
Learning effect saturation	0.86	0.97

and the reliability is high. The internal reliability analysis of 17 indicators shows that the alpha coefficient value is 0.95, indicating that the scale has high internal consistency and is a credible measurement tool.

Table 2 shows the validity analysis results of indicators by the RST method. The RD and SD values are less than 0.5, respectively; therefore, the evaluation indicator system for the questionnaire survey of virtual roaming system is effective.

TABLE 2. Validity test of evaluation system of virtual roaming system.

	Redundancy RD	Sensitivity SD
Virtual roaming system evaluation system	0.224	1.536

After determining the judgment matrix of the criteria at all levels, it is necessary to test the consistency of the constructed evaluation system for the evaluation system of virtual roaming system through Matlab 7.0 software. The calculation results are shown in Table 3, where the CR value of resource content saturation is 0.0126, information presentation saturation is 0.0158, resource presentation saturation is 0.0079, and the learning effect saturation is 0.0158. Since all the CR values and λ_{max} values are less than 0.1, the data are reasonable, the evaluation system has passed the consistency test, and the deviations are small.

TABLE 3. Normalization processing.

Evaluation dimension	Resource content saturation	Information presentation saturation	Resource presentation saturation	Learning effect saturation
λ_{max}	4.0339	3.0183	3.0092	3.0183
RI	0.9	0.58	0.58	0.58
CI	0.01131	0.0092	0.0046	0.0091
CR	0.0126	0.0158	0.0079	0.0158

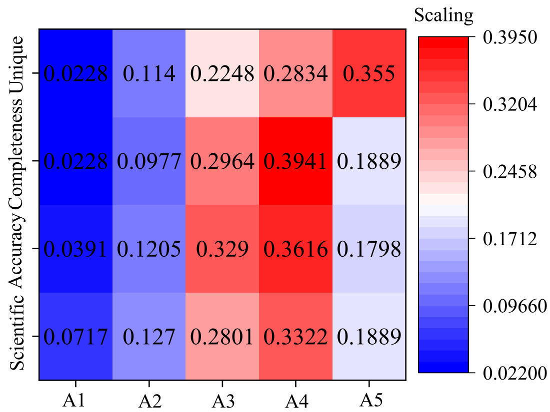

FIGURE 18. Evaluation results of resource content saturation.

C. RESOURCE CONTENT SATURATION

As shown in Figure 18, for the evaluation results of the system resource content, the analysis is performed from four aspects: scientific, accuracy, completeness, and uniqueness. The results show that: 33.2% of the users think that the system is more in line with science, 20% think that the system is not very good. For accuracy, 36.16% of the users think that the accuracy is more in line with historical facts, more than 80% agree on the accuracy of the designed system. For the integrity of resources, 40% of the users think that it is complete, and only 35.5% think that the system is unique but don't pay more attention to this based on the perception of the public. According to the above results, the content satisfaction of the virtual system resource is high, which is more scientific and accurate, but the uniqueness of the system needs to be further improved.

D. INFORMATION PRESENTATION SATURATION

As shown in Figure 19, to present the evaluation results for the information of the system, the three aspects of interface diversity, interface aesthetics, and interface quality are analyzed. The results show that: 37.1% of the users think that the system has good diversity, which can meet the needs of different groups of people; for the aesthetics of the interface, more than 80% think that it is very beautiful and satisfactory, of which more than 65% think the quality of the virtual museum is better than other products on the market. According to the above results, the virtual system information is well presented, but it still needs further improvement in terms of interface aesthetics and quality.

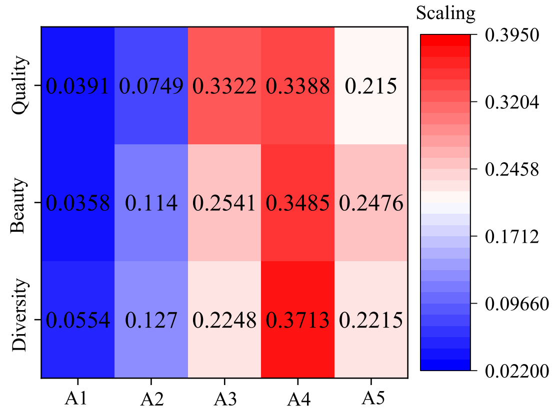

FIGURE 19. Evaluation results of information presentation saturation.

E. RESOURCE PRESENTATION SATURATION

As shown in Figure 20, for the resource presentation evaluation results of the system, the survey is performed from three dimensions: ease of use, openness, and controllability of resource presentation. The results show that more than 80% of the users think that the method of the system is simple and feasible, the function is more suitable for the public, and they can master its usage in a short time. Among them, 87% think that the designed system can be displayed and learned from multiple aspects so that the openness of the system is better, while 35% think that the control of the system is average, this may be because that more functions are needed. According to the above results, the virtual system learning is more acceptable to the public, and learners can easily learn to operate and spread through the Internet, allowing more people to accept and learn.

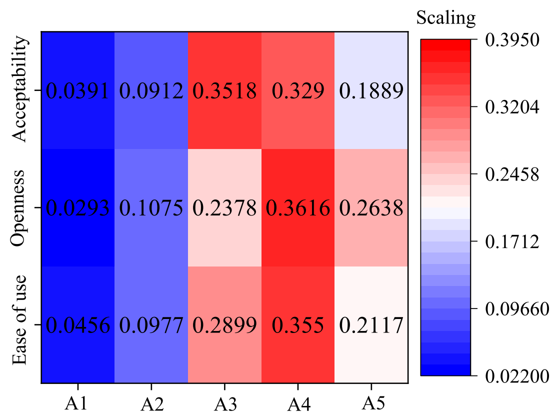

FIGURE 20. Evaluation results of resource presentation saturation.

F. LEARNING EFFECT SATURATION

As shown in Figure 21, it illustrates the evaluation results of the learning effect of the system. B1, B2, B3, and B4 respectively stand for "using the system can understand painting knowledge", "using the system can improve the appreciation ability", "using the system can improve the spiritual and cultural life", and "using the system can be more conducive to inheriting China Traditional Culture". The results show that nearly one-third of users believe that using this system can stimulate interest and motivation for learning to some extent. Among them, 38% of users believe that using the system can significantly improve their appreciation, 33.8% believe that using the system can significantly improve their spiritual and cultural life; another 31.3% believe that using the system can be more conducive to the inheritance of traditional Chinese culture. The above results prove that the learning effect of the virtual system is more obvious.

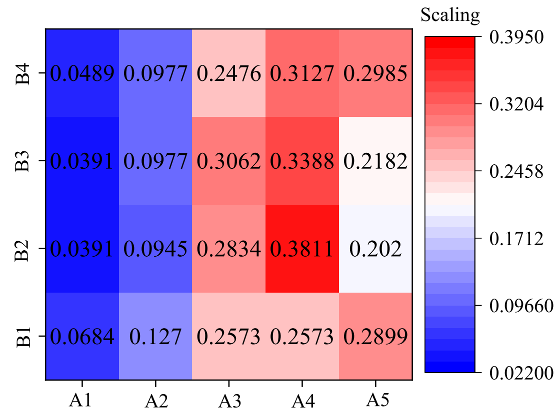

FIGURE 21. Evaluation results of learning effect saturation.

IV. DISCUSSION

A. COMMUNICATION VALUE OF THE DIGITALIZED MUSEUM OF ANCIENT HIGH-IMITATIVE CALLIGRAPHY AND PAINTING OF QAU

(1) The popularization of communication types: The purpose of a museum is to provide information to a wide range of users, including history, humanities, geography, and natural sciences [23]. According to the elements of communication, the museum should be the source of information, that is, the communicator [24], [25]. The information transmission of traditional museum is realized within the scope of the museum, and the most information recipients are the groups, which cannot achieve mass communication. Taking the visitors who visited the entity Museum of Ancient High-Imitative Calligraphy and Painting of QAU as an example, the process of the visit is nothing more than individual visits; the instructor explains to the individual visitors, which is exactly the same way that the instructor explains to the group visitors. These types of forms, according to the classification of communication in terms of communication types, include self-communication, interpersonal communication, and group communication. However, with the extensive utilization of digital technology in museums, the scope of the visitor has been greatly expanded and extended to the scope of the public, which is no longer blocked by the "walls" of the museums. In addition, the communication scope of collection and display of information in the museum has been

greatly expanded. On the basis of retaining the interpersonal and group communication functions of physical museums, the function of mass communication has also been added. First, the digitalization of museums meets the dynamic information needs of the public for cultural heritage protection and management, which is the function of monitoring; in addition, it realizes the evaluation and interpretation of culture, which is the function of publicity and education to the public, as well as realizing the attributes of the mass media organization of the museum.

Taking the Museum of Ancient High-Imitative Calligraphy and Painting of QAU as an example, traditional physical museum visitors are conducted in the form of individuals or groups, and the spread of the scope is limited, while the digital Museum of Ancient High-Imitative Calligraphy and Painting of QAU has broken through the restrictions of the ''walls'', allowing the majority of users to visit the museum at any time in any place, thereby realizing the mass communication of the Museum of Ancient High-Imitative Calligraphy and Painting of QAU.

(2) Interactivity in the communication process: The communication process of most traditional museums is a one-way flow of information [26]. Such a communication process has caused limited communication between the museum and the visitors. Often, users receive information from the museum but cannot effectively pass their feedback to the museum management in a timely and effective manner. Even if the museum issues questionnaire surveys to the crowds who come to visit for soliciting the opinions of the visitor, it will cause the problem of narrow investigation scope. More seriously, because the form and content of the questionnaire survey cannot be quickly modified according to changes in the actual situation, the information returned by the visitors is also indirect and lagging. During the visit of the Museum of Ancient High-Imitative Calligraphy and Painting of QAU, the visitor has watched in front of the exhibition board as the recipient of the information and listened to the explanation of the instructor. There are few opportunities to give feedback or to ask questions to the instructor. This type of communication is a mass communication method that does not have individual characteristics and lacks pertinence for each individual. At the same time, because the traditional museum visit model places the visitor as the absolute receiver of information, the blind acceptance of information by the visitor will reduce the visitor's initiative to receive information.

Due to the openness of time and space, the virtual museum under digitalization can make the users interact with the virtual museum through mouse clicks and finger touches, as well as selectively receiving the information of interest according to the users. Besides, the feedback of information to the museum realizes the two-way flow of information. Visitors no longer need to passively receive the information displayed by the museum in front of them as in the past; instead, they can choose the desired text and images according to their subjective ideas and real-timely communicate with the museum about what they are experiencing; so, the initiative of the visitors is well mobilized, and the efficiency and quality of the communication are improved. Compared with the traditional tour of the Museum of Ancient High-Imitative Calligraphy and Painting of QAU, whether interested or uninterested, visitors must visit the museum from the beginning to the ending according to the route of the tour. The final result is conceivable; the uninterested information is filtered out by their brains, while the interested information cannot be received well due to interference from other information. The effect of the visit will not be good with no doubts. This is not the case during the visit to the digitalized Museum of Ancient High-Imitative Calligraphy and Painting of QAU. Visitors can choose the information they are interested in to browse based on their personal preferences and manually filter out the interference of other information so that the quality of the information received is improved. At the same time, due to the manual selection process of the audience, their initiative has been greatly enhanced.

B. THE PRACTICAL VALUE OF THE DIGITALIZED MUSEUM OF ANCIENT HIGH-IMITATIVE CALLIGRAPHY AND PAINTING OF QAU

(1) Digital display function: With the development of computer technology, it has become possible to provide visitors with a multi-sensory enjoyment of sight and sound through text, screen images, sounds, and videos, and such a means has gradually become the mainstream [27]. The Museum of Ancient High-Imitative Calligraphy and Painting of QAU provides visitors with an unprecedented perception experience through multimedia forms of graphic images and audios, allowing visitors to choose their perception method according to their subjective wishes.

In the traditional display mode of the Museum of Ancient High-Imitative Calligraphy and Painting of QAU, the flow of information is one-way. As the recipient of the information, the visitors can only accept the information but cannot react to the museum. Here, the method improves the consensus and consistent experience between visitors, but weakens the differentiated perception experience of the visitors. With the help of digital technology, the QAU Museum of Ancient High-Imitation Calligraphy and Painting digitally changed the information and images of the display objects through the interaction with the digital display objects, resulting in a change in the meaning of the displayed objects. During the digital display of the QAU Museum of Ancient Highly Imitative Calligraphy and Painting, visitors only need a simple mouse click or keyboard operation to display they are interested in; also, they can rotate the viewing angle and make a detailed observation of the display. This is unimaginable in the traditional museum visits. The interactivity not only makes the visitors interested in the exhibits but also makes the virtual display objects have life and constantly changes.

The Museum of Ancient High-Imitative Calligraphy and Painting of QAU has been greatly extended in space and time. The first is the expansion of the content of the objects displayed in time and space dimensions. Because of the preservation limitations, in the physical Museum of Ancient High-Imitative Calligraphy and Painting of QAU, exhibits have to be locked in the display cabinet. The digital Museum of Ancient High-Imitative Calligraphy and Painting of QAU can provide visitors with complete digital images and attribute information of physical display objects through virtual technology. In the virtual QAU roaming system, visitors can adjust their perspective and observe the display objects from multiple angles to observe the parts and details of the objects so that they can master the connotation information and structural information from all angles. Second, the time and space for visitors to visit the exhibition has been expanded. Because the digital virtual QAU roaming uses digital means to copy and spread, visitors no longer need to rush to the Museum of Ancient High-Imitative Calligraphy and Painting of QAU exhibition on the ground at a specific time. In the digital museum, users can visit anytime and anywhere without any limits.

(2) Digitalized protection function: The Museum of Ancient High-Imitative Calligraphy and Painting of QAU have collected more than 100 high-imitative paintings and calligraphy works printed by Nigensha Japan, including fine paintings and calligraphy works in Tang, Song, Yuan, Ming, Qing, and other ancient Chinese dynasties. The collected works cover three painting subjects of characters, landscape, and flowers and birds, all of which are master-class fine works, such as Fan Kuan's *Xi Shan Xing Lv* and Li Tang's *Wan He Song Feng Tu* in the Song Dynasty, Huang Gongwang's *Fu Chun Shan Ju Tu* in the Yuan Dynasty, Shen Zhou's *Lu Shan Gao* in the Ming Dynasty, and fine works of famous ancient Chinese artists Ni Zan, Tang Yin, Shi Tao, and Wang Yuanqi. These works have been stored in the exhibition hall for a long time, which may cause damages to some extent. Digital technology provides a new means and channel to protect these ancient high-imitative calligraphy and painting works. Through digital means, the high-imitative calligraphy and painting works in the QAU museum are digitized. Since the digitized works can be continuously copied and stored on the premise of maintaining integrity, the collections in the Museum of Ancient High-Imitative Calligraphy and Painting of QAU can get rid of the damages caused by the passage of time and maintain their original appearances for a long time.

Besides, for any building, no matter how large the building scale is, it will have a corresponding capacity according to its characteristics. For the Museum of Ancient High-Imitative Calligraphy and Painting of QAU, the museum management has to take restrictive measures when the number of tourists is large to prevent the number of visitors visiting at the same time from exceeding the upper limit of the daily tourist volume; however, for ordinary tourists, this delays the visiting time, and they have to spend their time waiting in line outside the museum. The virtual the Museum of Ancient High-Imitative Calligraphy and Painting of QAU relieves the pressure of tourists to some extent. Due to the infinite reproducibility of numbers, anyone can visit the Museum of Ancient High-Imitative Calligraphy and Painting of QAU through the terminal at any time and any place, which has a good diversion effect for visitors; in addition, the digital museum can reduce the number of visitors visiting the physical museum, which is beneficial for protecting and extending the service life of the QAU Museum of Ancient High-Imitative Calligraphy and Painting.

(3) Digital collection function: The digital collection includes the collection and preservation of information related to the works. The digital objects are stored in the form of data through digital processing, such as the digital shooting of the works and virtual production of 3D models [28]. In the preservation process of traditional museum exhibits and related materials, in addition to the tedious process, it also requires dedicated personnel to integrate and manage the physical objects. This not only consumes a lot of time, during which the management personnel need to spend a lot of energy in the entire management process, but also requires enough storage space to save these physical exhibits. Taking the traditional Museum of Ancient High-Imitative Calligraphy and Painting of QAU as an example, the management of all exhibits in the museum requires staff with professional management skills, and many such professionals are required. Even for the same exhibit, it needs continuous maintenance and management to understand the latest status of the exhibit in real-time, which requires a lot of manpower and financial resources. In addition, all exhibits need to be prepared with enough space for preservation during the preservation process. In this way, a large amount of storage space needs to be consumed, which means that QAU must have a lot of space to support the venue.

In terms of digital collections, virtual museums have advantages that traditional museums do not. Because virtual museums store information in the form of zero and one data, it can save a lot of storage space; furthermore, because of the ease of data maintenance, without human interference, the data will not be destroyed, so there is no need for special guards, no time and space restrictions, and no requirements for long-term storage of information resources, thereby saving manpower and resources [29]. It is precisely because the information in the form of data is easy to be operated in terms of input, query, modification, and deletion that makes the digital exhibits in the virtual museum easy to be added, managed, queried, updated, and maintained. Digitally stored museum exhibit information can be preserved for a long time and is not easily affected by the environment, ensuring that the collection can be better collected, reducing the possibility of cultural relics being damaged by natural environment and objective factors, and keeping the collection longer. The characteristics of the Museum of Ancient High-Imitative Calligraphy and Painting of QAU include convenient and lasting, convenient and fast maintenance, manpower saving, and material resource saving. Besides, the information of the collection is not easy to be destroyed. Not only is it conducive but also counterproductive to the promotion of the Museum of Ancient High-Imitative Calligraphy and Painting of QAU. In turn, the protection of the Museum of Ancient

High-Imitative Calligraphy and Painting of QAU promotes its further development.

C. THE AESTHETIC VALUE OF THE DIGITALIZED MUSEUM OF ANCIENT HIGH-IMITATIVE CALLIGRAPHY AND PAINTING OF QAU

When digital technology first appeared, people had no understanding of this emerging field, and it was impossible to realize the immense energy and value contained in it. But as technology is gradually recognized and mastered by people, the simple technical level of understanding begins to change into a higher level of arts integration. But in turn, high-level artistic aesthetics require a large number of underlying technologies as support. So, advanced aesthetic requirements have played a certain role in promoting the development of technology [30].

The characteristics of aesthetic activities include intuitiveness, emotion, and pleasure. These three characteristics are the advantages of digitalization [31]. The characteristics of aesthetic activities include intuitiveness, emotion, and pleasure. These three characteristics are the advantages of digitalization. In terms of digital display, digital technology is used to display museum information for the visitors. It is precisely because of this advantage that this display method is artistically aesthetic. It can convey beauty to the public and maximize the subjective initiative of the public. As the application of digital graphics and image technology in the Museum of Ancient High-Imitative Calligraphy and Painting of QAU, the museum has a strong professionalism and rich artistic quality at the same time. Since the visual graphic images are displayed in front of the visitors, the visitors can judge the beauty and ugliness of the images through their subjective experiences. Therefore, the process of visiting the Museum of Ancient High-Imitative Calligraphy and Painting of QAU is itself an aesthetic process.

V. CONCLUSION

Here, the QAU is taken as the research object. Through the virtual roaming system design of the venues and representative exhibition items in the Museum of Ancient High-Imitative Calligraphy and Painting of QAU, the virtual roaming of the Museum of Ancient High-Imitative Calligraphy and Painting of QAU is realized in terms of the visual interface and interactive function development; users can utilize computer peripheral devices to perform interactive browsing and access, achieving the spread and display of multiple multimedia forms from images to videos. A comprehensive evaluation from the aspects of resource content, information presentation, resource presentation, and learning effect has found that compared with the physical museum, the digitalized QAU Museum of Ancient High-Imitative Calligraphy and Painting has new features of bilateral interactive display and collaboration of multiple senses in coordination with display methods. For the collection of exhibits, it has the characteristics of saving space, damage avoiding, and easy to query and manage. By displaying the information through the advantages of graphic images, the recipients of information can participate in the selection of information sources according to their aesthetics, which provides a means for the beautification and display of the museum exhibits. However, due to the complexity of the virtual roaming of the building and the artistic features it embodies, as well as the limited nature of the data, the diversity of the digital process methods and the difference in the final effect are understood deeply, as well as the complexity of the artistic characteristics reflected thereby, which needs to be followed up and deepened in the future.

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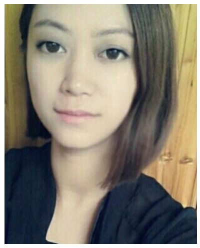

JING LI graduated from the China Academy of Arts.

She is currently an Assistant Professor with Qingdao Agricultural University. She mainly works on artistic creation and art theory research. In November 2015, her work Food for the Sky was selected into the First China Comprehensive Materials Painting Biennale hosted by the Chinese Artists Association. In September 2018, her article A Brief Analysis of the Characteristics of the Social Reality Theme Creation—Viewed from the Most Beautiful Chinese Large-Scale Art Exhibition was selected as the first National Art Summit Forum hosted by the Chinese Artists Association. In November 2019, my work Love Letter—to You Who Was Young was selected into the 23rd National Printmaking Exhibition organized by the Chinese Artists Association.

NING YU is currently an Associate Professor with the College of Art, Qingdao Agricultural University. She has hosted one subsidiary subject of National Social Science Fund in Art and one provincial key subject of Art Science. She has also participated several planning research of provincial Social Science.