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Algorithm-Empowered Research on the Digital Preservation and Innovation of Mang Weaving Techniques

Yan Pan[1] and Yanyan Chen[1,*]
[1] GUANGXI TECHNOLOGICAL COLLEGE OF MACHINERY AND ELECTRICITY, Nanning, Guangxi, 530000, China
Corresponding authors: (e-mail: chenyanyan@gxcme.edu.cn).

Abstract The digital development of intangible cultural heritage is becoming one of the research hotspots of cultural heritage. In this paper, we integrate the improved quadratic error metric (QEM) algorithm with the AI technique of multi-layer narrative framework to realize the digital conversion of the mang weaving technique. By introducing the double weighting factors of vertex discrete curvature and local area to optimize the mesh simplification process, the detail retention of the digital model of mang weaving is enhanced. Combine the perception-behavior-emotion three-layer interactive narrative design to construct the digital museum of mang weaving. Practice shows that the Mangzhu digital model of this paper's method is better than the comparison method in 2 indicators: generation resolution and generation efficiency. There are 80%-100% of the experiencers gave 85 points and above to the digital museum visiting experience. The average satisfaction score of the digital museum was 4.00, 4.00, 4.00, 4.00, 4.00, and 4.25, which is high.

Index Terms QEM algorithm, discrete curvature, double weighting factor, interactive narrative, mango-coded digital museums

I. Introduction

Non-legacy skills, carrying the historical memory and cultural genes of a nation, are the product of the wisdom of our forefathers. However, in the rapid development of modern society, these precious skills are facing many serious challenges. With the acceleration of urbanization, a large number of young people have poured into cities, and the traditional lifestyles of rural areas have undergone great changes, which has deprived the soil for the inheritance of intangible cultural heritage skills that depend on specific regional environments and life scenes, such as some traditional hand-knitting skills, due to the complex learning process and low economic benefits, young people have little interest in them, and the older generation of inheritors are getting older, and the skills are in danger of being lost [1]-[3].

At the same time, the dissemination of non-heritage skills is limited. The traditional way of dissemination and innovation mostly relies on oral teaching and on-site demonstration, etc., which is slow and narrow in coverage, and it is difficult for the outside world to understand its unique charm, which also limits the influence and vitality of NRH skills [4], [5]. Moreover, the preservation of non-heritage skills is difficult. The raw materials used in some traditional skills are scarce and difficult to be preserved, and the tools and equipment in the production process are also easily damaged, such as some traditional weaving crafts, the quality of the weaving materials is extremely high, and it is difficult to identify the intellectual property rights of the weaving crafts, which further exacerbates the difficulty of protection [6]-[8]. Digital technology has brought new opportunities for the protection of non-heritage skills, which is of great significance and cannot be ignored. The use of digital technology and equipment can realize high-definition, complete and permanent records of non-heritage skills, achieve wide dissemination with the help of the Internet platform, as well as the innovative development of traditional skills such as digital simulation technology [9], [10].

At present, Guangxi has been included in the list of intangible cultural heritage at the autonomous region level with a total of 58 items, which are gradually moving towards the stage of digital protection [11]. As an intangible cultural heritage with strong local cultural characteristics, the traditional skill of mango weaving has been widely recognized, and the “mango weaving skill” has been selected as one of the first batch of traditional craft revitalization projects at the autonomous region level in Guangxi. Artificial intelligence, as a widely used technology, occupies an important position in the digital protection and inheritance of cultural heritage [12]. The protection, inheritance, dissemination and innovation of Guangxi's traditional skills of mango weaving by means of artificial intelligence will inevitably become a requirement for the protection of non-heritage at the local level.

In this paper, we introduce a traditional LOD technique using a uniform simplification strategy to extract the weaving structure of mango-woven artifacts. Aiming at the limitation of key feature attenuation in the extraction process, an enhancement scheme incorporating geometric feature analysis is proposed. The QEM algorithm used is optimized and simplified through two-factor constraints such as discrete normal vector and curvature estimation, local area control, and so on, to reduce the complexity of the mango weaving modeling while preserving its geometric features. In terms of digital application, a three-layered narrative framework is designed to enhance the sense of cultural interaction and immersion, and a visual fidelity-behavioral guidance-emotional resonance digital museum of Mangzhu is established to realize digital conservation.

II. Digital museum realization of mango weaving technique based on AI technology

II. A. Generation and drawing of virtual scene level-of-detail (LOD) models

In computer graphics, the object model in a scene is usually described by a polygonal mesh, in order to control the complexity of the scene and speed up the graphics drawing speed, it is a very effective method to provide different levels of LOD model for the objects.The LOD model is usually generated by a mesh simplification algorithm (Quadratic Error Metric QEM algorithm). Mesh simplification is to minimize the number of vertices by some methods to represent the original model with an approximate model while maintaining the appearance characteristics of the original mesh model. The simplification is usually achieved by removing from the polygon mesh those tuples (vertices, edges, or triangles) that do not have a significant impact on the appearance of the model or are considered “less important”.

II. A. 1) Improved algorithm for quadratic error metric (QEM) based on visual effects

Although the QEM algorithm is ideal in terms of mesh model simplification speed, it also has some disadvantages. From the simplification results, the QEM algorithm only considers the distance metric, and does not consider other weighting factors to calculate the cost of edge contraction, which produces a more uniform mesh distribution, and after large-scale simplification, there will be a loss of important geometric features on the surface of the model, which in turn is likely to cause the loss of the detail feature part. Since the mango-woven artifacts in museums are generally more delicate, it is necessary to consider the detailed part of the simplified model to maintain the key features of the mango-woven artifacts model, so this paper proposes an improvement based on the QEM algorithm, which is improved through the introduction of the vertex discrete curvature and the area of the local region as two weighting factors to control the simplification error of the model.

II. A. 2) Weighted error measures for curvature and area

In differential geometry, curvature is a measure of the degree of unevenness of a surface or geometry, the greater the curvature the greater the degree of curvature. Therefore, the curvature can be used to characterize the local details of the mesh model, for example, the curvature of the characteristic areas such as corners and sharp points in the mesh tends to be larger, while the curvature of the flat areas such as planes and slopes tends to be smaller. Therefore, this paper uses this to determine the local features of the geometric model to ensure the quality of the simplified model.

The simplified quality of the model is controlled by introducing the local area. In the feature area of the original mesh model, the mesh is generally denser, and its corresponding local area is also smaller, the simplification operation on this part of the region is easy to cause the loss of detailed features of the model, so it is very necessary to use the local area as a measure of the feature area.

Therefore, in this paper, from the above two points, firstly, the curvature of all vertices in the mesh model is sorted, and the order of contraction is delayed for the regions with larger curvature, and the edge folding operation is prioritized from the regions with smaller curvature, so that the key features of the mesh model can be retained; then, the feature point is judged according to the size of the curvature and the local area of the region of that feature point is derived; finally, the curvature of every vertex in the mesh and the local area of the corresponding feature point are introduced into the quadratic error matrix. Finally, the curvature of each vertex in the mesh and the local area of the corresponding feature point are introduced into the quadratic error matrix to guide the edge folding order of the mesh model. By introducing the two weighting factors of vertex discrete curvature and local area, more detailed features of the model can be retained more effectively, which can produce a visual effect more similar to the original model.

1) Discrete normal vector and curvature estimation

The normal vector and curvature of the surface can be used as important metrics to represent the local details of the mesh model, such as creases, inflection points and other curved areas. The normal vector of a surface is the first-order differential component of the surface, and the curvature is the second-order differential component of the surface. Since the artifact mesh model constructed in this paper is represented by a triangular mesh, the surface formed by the mesh model is a discrete surface representation without continuous normal vectors and curvatures.

The discrete normal vectors and curvatures at the corresponding vertices are usually computed as the degree of curvature of that mesh surface at the vertices.

Discrete normal vectors. There are several ways to define the discrete normal vector on a triangular grid, and the different methods will have a great impact on the estimation of the discrete curvature. In this paper, we first give a method to compute the unit normal vector of a triangular mesh. From the geometric elements constituting a triangular mesh, it can be seen that a triangular mesh is usually represented by the vertex set $V=(v_1,v_2,\ldots,v_n)$, the edge set $E=(e_1,e_2,\ldots,e_l)$, and the triangular set $T=(t_1,t_2,\ldots,t_m)$, where V, E, and T respectively denote the set of all vertices, edges and triangles around vertex v_i. (Figures are mentioned in the text but no specifics are presented; no additions are made as requested)

For any triangular face piece in the mesh can be represented by (v_{i-1},v_i,v_{i+1}), then the unit normal vector of the triangular face piece is:

$$n_i=\frac{(v_{i-1}-v_i)\times(v_{i+1}-v_i)}{\left|(v_{i-1}-v_i)\times(v_{i+1}-v_i)\right|} \tag{1}$$

Using the area of the triangle associated with the vertex v_i as weights, the unit normal vectors on each face are weighted and averaged to obtain the unit normal vector at that point. The expression is given below:

$$n_v=\frac{\sum_{j=1}^{m}n_j s_j}{\left\|\sum_{j=1}^{m}n_j s_j\right\|} \tag{2}$$

where s_j denotes the area of the jth triangle adjacent to the vertex; m is the number of triangles adjacent to the vertex. The unit normal vector at each vertex can be computed and stored by Eq. (2).

Discrete curvature. Discrete curvature can be computed in several ways, of which Gaussian curvature is the most commonly used. It defines the two principal curvatures of the surface at any point v as k_1 and k_2, then the Gaussian discrete curvature k at that point is defined as $k=k_1\times k_2$. The absolute value of the Gaussian curvature k is geometrically important and reflects the degree of curvature of the surface In order to estimate the Gaussian curvature of the vertices in a triangular mesh, we often use the following formula for estimation:

$$K_v=\frac{2\pi-\sum_{n}\theta_v}{S_\Sigma(v)} \tag{3}$$

where θ_v is the neighboring pinch angle of vertex v; n is the number of triangles associated with vertex v; and $S_\Sigma(v)$ is the sum of the areas of the triangular meshes neighboring vertex v, i.e., the local region area (LRA). We store the Gaussian curvature at a vertex as an eigenvalue of that vertex. Since this curvature is an intrinsic geometric invariant, it can well characterize the degree of curvature of the surface at the point v, which is important for maintaining the local features.

2) Localized Region Area

The local region area (LRA) is the area of the local region that changes during the execution of the simplification process, which mainly examines the effect of edge folding on the area of the triangular mesh region associated with it. Usually the mesh characteristics of the region, the mesh density is dense, the triangle area is small, the local area is also relatively small, the edge folding operation will cause the loss of model features, so the algorithm in this paper will be used as a feature retention control factor, which can effectively control the model simplification error.

Combining the above we can get the cost of edge folding, first define the two endpoints of any edge L in the triangular mesh as (v_1,v_2), and their Gaussian curvatures are K_{v_1} and K_{v_2}, then the Gaussian curvature of the edge L can be expressed by the following expression:

$$K(L)=\left|K(v_1)\right|\cdot w_1+\left|K(v_2)\right|\cdot w_2 \tag{4}$$

where w_j is the Gaussian curvature weight coefficient of the vertex, which can be obtained by the following equation:

$$w_j=\frac{S_\Sigma(v_i)}{S_\Sigma(v_1)+S_\Sigma(v_2)},i=1,2 \tag{5}$$

Then the Gaussian curvature of the edge L can be expressed as:

$$K(L)=\left|\frac{2\pi-\sum_{n}\theta_1}{S_\Sigma(v_1)}\right|\cdot\frac{S_\Sigma(v_1)}{S_\Sigma(v_1)+S_\Sigma(v_2)}+\left|\frac{2\pi-\sum_{m}\theta_2}{S_\Sigma(v_2)}\right|\cdot\frac{S_\Sigma(v_2)}{S_\Sigma(v_1)+S_\Sigma(v_2)}$$
$$=\frac{\left|2\pi-\sum_{n}\theta_1\right|+\left|2\pi-\sum_{m}\theta_2\right|}{S_\Sigma(v_1)+S_\Sigma(v_2)} \tag{6}$$

Then we can newly define the discrete curvature of each vertex in the mesh as:

$$K(v)=K(L_v)\cdot K_v \tag{7}$$

where $K(L_v)$ is the Gaussian curvature of the edge containing vertex v and K_v is the Gaussian curvature of vertex v.

The discrete curvature associated with each vertex and the area of the local region of the triangular mesh adjacent to it are obtained according to the above equation, and then according to the principle of the QEM algorithm, the new quadratic error matrix $Q'(v)$ of each vertex is obtained, which is the error matrix obtained after weighting by the above two weighting factors, and it can be expressed by the following equation:

$$Q'_{v_i}=\frac{K(v)}{LRA(v)}\cdot Q_v=\frac{K(v)}{S_\Sigma(v)}\cdot Q_v \tag{8}$$

Then the new folding cost can be expressed as follows: if $(v_1,v_2)\rightarrow\tilde{v}$, its contraction cost is:

$$\Delta'(\tilde{v})=\tilde{v}^T(Q'_{v_1}+Q'_{v_2})\tilde{v} \tag{9}$$

The detailed features of the model can be well preserved by using the edge folding cost obtained from the above equation. Because in the triangular mesh, the mesh near the feature edge is denser, which causes its local area to be smaller and the discrete curvature at that place is larger, thus making its contraction cost weighted by the above two weighting factors to become larger, and then it will be at the back of the edge contraction queue, which delays the contraction of the feature edge, and thus preserves some important features of the model.

II. B.Interactive Narrative Design Methods for Digital Museums

From the analysis of the composition of interaction narratives in digital museums, it can be concluded that the user's cultural experience is a process from cultural perception to cultural learning and then forming cultural emotions. First of all, the user receives the cultural information through the senses, and the way to receive this information smoothly is the user's interactive behavior on the digital platform, which is related to the interaction design of the digital platform, and a good interaction design can promote the user's understanding and learning of the content. And what really impresses users is the core content of cultural heritage, which helps users form a long-lasting cultural and emotional memory. Therefore, this paper proposes the design method of digital museum interaction narrative from the three levels of perception layer, behavior layer and emotion layer to improve the user experience in cultural perception, cultural learning and cultural emotion.

Figure 1 shows the layers of digital museum cultural experience design. The perception layer relates to the user's first feeling of use, i.e., the user's physiological reaction, which is directly related to the user's instinctive preference and emotional reaction when using the digital museum, and is mainly affected by the picture performance of the narrative content, as well as the interface design of the digital platform and the design of the sound effect, etc.; the behavior layer relates to the user's actions and choices during the process of use, and needs to consider the realization of the functions of the digital museum and whether the storyline promote further actions of the user, there are four elements of a good behavioral level design - function, comprehensibility, ease of use and feeling; the emotional layer determines the user's overall evaluation of the experience process, affects the user's long-term emotions and memories, and is the most important part of the cultural experience. The fulfillment of the emotional layer is affected by factors such as the user's life experience and cultural level, and in the design of digital museums is mainly played by the content of the story and the theme idea.

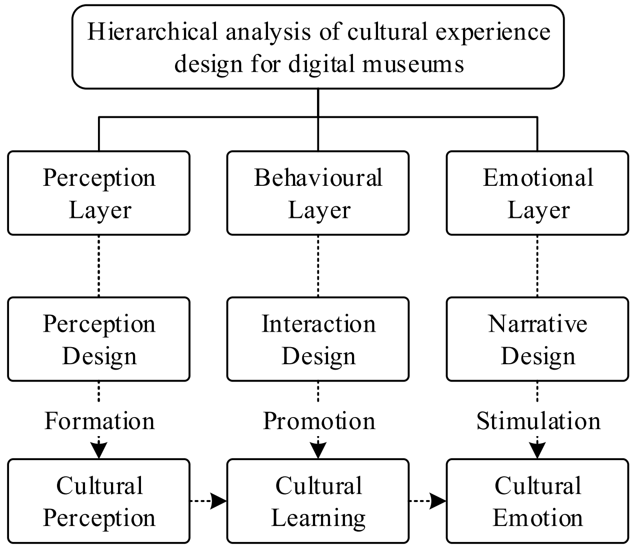

Figure 1: The levels of cultural experience design in digital museums

II. C.Digital Museum of Traditional Mango Weaving Techniques

The digital museum of traditional mango weaving techniques is generally set up on specialized or related platforms and institutions, such as online and offline museums, exhibition halls and handicraft training institutions to establish a virtualized digital display platform, and through the establishment of a digital archive, records and preserves the planting and harvesting of raw materials for mango weaving, the specific and clear process of the craft techniques, and the demonstration of the finished products of the craft of mango weaving, so as to provide audiences with a comprehensive understanding of the image of the craft, the change of the craft, and the related knowledge system of the traditional techniques of mango weaving. In this way, the audience can have a comprehensive understanding of the image of the craftsmanship of the traditional skills of mango weaving, the changes in the skills and the related knowledge system.

The digital museum needs to be established with the traditional skills of mango weaving as the center, the government as the support, the display platform as the backing, and the digital technology as the engine, in order to establish a joint collaboration in place, in which the team with relevant technical expertise, the support of the government and relevant institutions, and the cooperation of universities and research institutions are all indispensable parts of the museum on the road to the realization of the form of digitization.

III. Digital museum application of mango weaving technique based on AI technology

III. A. Comparison of model generation plotting effects of different methods

III. A. 1) Comparison of resolution

In order to determine whether the method of this paper generates the drawn mango braid model with good visual effect, the progressive error generation method and the maximum error generation method are chosen as the comparison method to compare the resolution of the model generated by different methods. Figure 2 shows the comparison results. The method in this paper can more effectively retain the more detailed features of the mango weaving model and produce visual effects more similar to the original model. In the process of generating the mango weaving model from 0-1500 frames, the generation resolution of this paper's method is higher than that of the comparison method in most of the frames, which basically maintains the resolution above 90.00% and reaches 98.67% at the highest. The maximum resolution of the generated model for the progressive error generation method is only 77.71%, and the maximum error generation method has a maximum resolution of 90.96%, with most of the frames having a resolution between 70.00% and 85.00%. The mango weaving model generated by the method in this paper has a clearer visualization of the specific details of the mango weaving technique on the finished product.

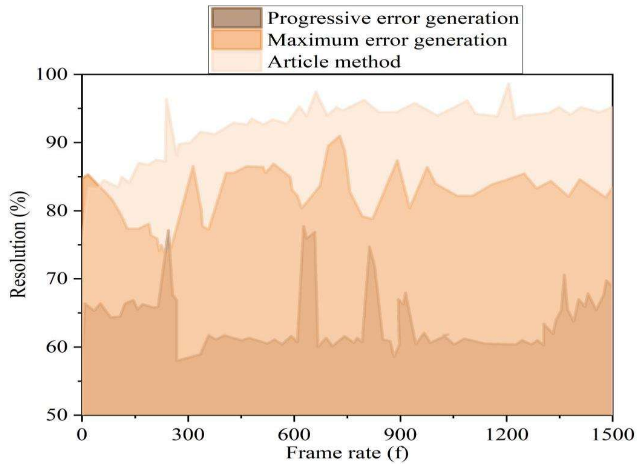

Figure 2: Resolution comparison of models generated by different methods

III. A. 2) Comparison of generation speed

In addition to the resolution of generating the mango-coded model affects the user's interactive experience, the speed of model generation also has a large impact on the sense of immersive experience. Compare the model generation speeds of the above three methods to determine the advantages of this paper's method. Figure 3 shows the results of the speed comparison of generating models by different methods. In the process of generating 0-1500 frames digital model, the generation speed of this paper's method stays below 10ms/f, which is higher than that of the two methods, which is below 60ms/f and below 45ms/f. And the generation speed of this method is more stable. Thus, it is judged that the method in this paper can generate the detailed mangled digital model more quickly and smoothly.

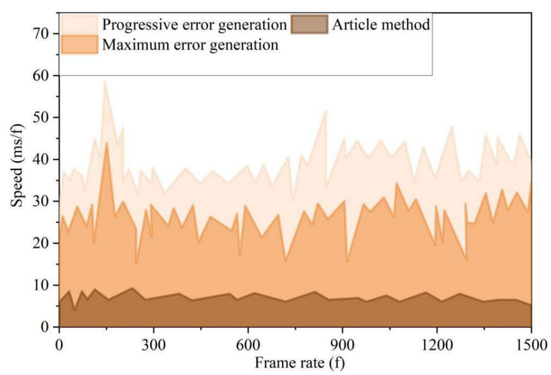

Figure 3: The speed comparison of generating models by different methods

III. B. Evaluation of the Visiting Experience of the Digital Museum of Mango Weaving Technique

III. B. 1) Evaluation of Student Visiting Experience

Build an online digital museum of mango weaving skills using designed mango weaving models and other resources to provide visitors with an interactive experience. Invite 10 students and 10 teachers of different age groups as volunteers to participate in the interactive activities of the online digital museum of mango weaving techniques. At the end of the experience, the evaluation data of the students and teachers on the digital museum were collected through questionnaires to judge the effect of the construction of the digital museum of mang weaving.

Table 1 counts the experience evaluation of 10 students of different age groups. In the six evaluation dimensions of the overall style evaluation of the museum, the evaluation of the display effect of the Mangzhi model, the evaluation of the UI interface design, the evaluation of the design of the Mangzhi technique, the evaluation of the video image playback, and the evaluation of the Mangzhi cultural and creative products, there are 8, 10, 9, 8, 8, 8, and 10 students who gave more than 85 points respectively, which accounted for 80-100% of the total number of evaluators, which shows that the constructed Mangzhi Digital Museum can simultaneously meet the students' different experiential needs, and achieves the purpose of creation, so that more young people can understand the skill of mang weaving and thus join in the digital conservation and creation.

Table 1: Experience evaluations of 10 students of different age groups

Evaluation index	Grade score			
	Excellent (100-95)	Good (95-85)	Middle (85-75)	Pass (75-65)
Overall style evaluation of the museum	3	5	2	0
Evaluation of the display effect of the awn-woven model	6	4	0	0
UI interface design evaluation	4	5	1	0
Evaluation of the experience of the straw weaving technique	5	3	2	0
Video image playback evaluation	4	4	2	0
Review of Mangbian Cultural and Creative Products	5	5	0	0

III. B. 2) Evaluation of Teachers' Visiting Experience

Table 2 shows the evaluation results of teachers' visiting experience. For the same six evaluation dimensions, the number of teachers who gave 85 or more points reached 10, 8, 8, 9, 10, 10, respectively, accounting for the same percentage between 80% and 100%, and three dimensions of the evaluation of the visit experience received 100% good or excellent scores. For the teachers who participated in the experience, the Mangzhu Digital Museum was constructed to meet their experiential needs.

Table 2: Evaluation results of teachers' visit and experience

Evaluation index	Grade score			
	Excellent (100-95)	Good (95-85)	Middle (85-75)	Pass (75-65)
Overall style evaluation of the museum	7	3	0	0
Evaluation of the display effect of the awn-woven model	5	3	2	0
UI interface design evaluation	6	2	2	0
Evaluation of the experience of the straw weaving technique	7	2	1	0
Video image playback evaluation	5	5	0	0
Review of Mangbian Cultural and Creative Products	6	4	0	0

III. C. Online Digital Museum Satisfaction Analysis

Students and teachers participating in the experience were further invited to fill out a standardized satisfaction scale through the setup. The satisfaction standardized scale was set up with five questions covering various design aspects of the Munz Online Digital Museum. The scale is based on a 5-point scale, with 5 points for very satisfied and 1 point for very dissatisfied. For presentation purposes, students and teachers are numbered from 1-20. Table 3 shows the results of the satisfaction standardized scale. From the record sheet of the results of the completed satisfaction standardization scale, the questions generally scored between 3-5, and the average of the five questions was 4.00, 4.00, 4.00, 4.00, 4.00, 4.25, and the student users and teachers who participated in the experience were generally satisfied with their experience of the online digital museum.

Table 3: The results of the standardized satisfaction scale

	Question 1	Question 2	Question 3	Question 4	Question 5
1	4	5	4	4	5
2	4	3	5	5	4
3	5	4	4	3	5
4	4	4	4	5	3
5	4	4	3	5	5
6	5	4	5	5	4
7	4	5	5	5	5
8	3	5	4	3	5
9	4	3	4	4	3
10	4	4	5	4	4
11	3	3	3	4	4
12	5	3	4	5	5
13	4	5	5	5	5
14	5	4	4	4	5

15	4	3	3	4	5
16	5	5	5	4	4
17	3	4	3	5	4
18	5	5	4	3	4
19	5	5	5	5	5
20	4	3	4	3	4
Mean value	4.00	4.00	4.00	4.00	4.25

IV. Conclusion

This paper introduces the QEM improvement algorithm based on visual effect to enhance the feature extraction accuracy of mang weaving artifacts, and at the same time constructs a mang weaving digital museum with good interactive performance to realize the digital protection of mang weaving skills. After the study, it is found that: 1) the resolution of the mang weave model generated by this paper's method is more than 90.00%, and the generation speed is stable at 10ms/f, and the model generation performance is due to the comparison method. 2) after 20 experiencers visited and experienced the mang weave digital museum, 80%-100% of the experiencers gave more than 85 points, and the digital museum can satisfy a variety of experiential needs of the experiencers. 3) the experiencers' satisfaction with the mang weave digital museum is very high. The average satisfaction of the Mangzhi Digital Museum of the participants is 4.00, 4.00, 4.00, 4.00, 4.00, 4.25, which verifies the effectiveness of the creation of the museum. In the future, generative AI technology can be introduced to realize the digital innovative design of the Mangzhi technique and increase the interest of the experiencers in the Mangzhi Digital Museum.

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