Data-Driven Technology Augmented Reality Digitisation in Cultural Communication Design

A Case Study from Qinhuai Lantern Festival ICH

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***Abstract*—The digitalisation of intangible cultural heritage and big data technology provide great potential for the development of intangible cultural heritage in low-carbon reform tourism, which not only increases the accuracy of AR digital design, but also contributes to the management and protection of intangible cultural heritage based on tourism. Aiming at the lack of testing and evaluation process of the current tourism intangible cultural heritage AR digital design process, this paper proposes an intangible cultural heritage AR digital design testing algorithm based on data-driven technology using Qinhuai lanterns and colours as a case study. Firstly, an AR digitization scheme based on Qinhuai lanterns intangible cultural heritage is designed; then, around the scheme, key technical contents of AR digitization design of intangible cultural heritage are analysed; secondly, combining the dragonfly algorithm with the restricted Boltzmann machine model, a test method for the AR digitization design of tourism intangible cultural heritage of low-carbon reform based on the optimization of the structural parameters of restricted Boltzmann machine by the dragonfly algorithm is put forward; lastly, relying on the collected data, the design of the AR digital design model of Qinhuai lanterns and colours tourism, and also analysed the effectiveness of the intelligent testing algorithm proposed in this paper. The results show that the proposed digital design method is effective, while the optimised test method has improved convergence speed and increased accuracy, and the test score prediction accuracy reaches 93.5%.**

Keywords*—Intangible cultural heritage AR digitization; low-carbon tourism; design test analysis; dragonfly algorithm; restricted Boltzmann machine model

I. Introduction

In recent years, with the rapid development of digital information technology, the use of information technology and intelligent algorithm technology to identify, store, display and disseminate the intangible cultural heritage (ICH) has become an important way of intangible heritage heritage inheritance and protection, which makes the digitisation of intangible heritage a hotspot of concern in the field industry and academia [1]. As a unique cultural phenomenon and spiritual wealth, intangible culture not only meets people's spiritual needs, but also enhances the attractiveness of regional tourism [2]. With the rise of Augmented Reality (AR) technology, the digitisation of ICH has made a qualitative breakthrough and development, which provides new ideas for the digital design and display of intangible genetic culture [3]. At the same time, the development of big data technology, cloud computing technology, and intelligent algorithms has provided strong support for the collection, collation and analysis of intangible heritage [4]. Currently, with the combined application of AR technology and various types of ICH, the focus of the research falls on the AR digital design process, the lack of research on the testing method of the AR digital design effect of ICH, and at the same time, taking into account the factor of low-carbon tourism, the AR digital design algorithms of intangible culture for low-carbon tourism are even more scarce [5]. Therefore, the research of AR technology and data-driven algorithms in the digital design and analysis method of ICH in low-carbon tourism has become the development trend of theoretical research and realistic problem-solving research.

Currently, the digital research of ICH mainly includes ICH digital acquisition technology, storage technology, production technology, dissemination technology, and design and analysis technology [1]. Bai and Boo propose a digital exhibition prototype system based on mixed reality technology for the digitalisation of physical museum exhibitions [6]. Tu and Jiang combine immersive virtual reality technology and proposes a digital experience method for museums [7]. Gireesh investigates 3D digital intangible genetic dissemination methods [8]. Yingji explores the application of AR technology in the digital design and display of intangible genetic culture [9]. Li et al. [10] studied an online museum roaming system based on virtual genetic digitisation technology. By analysing the existing literature research, the following problems exist in the digitization technology of intangible genetic culture based on AR technology: 1) the digitization of intangible genetic culture lacks the research of specific detail technology as well as the performance analysis; 2) the research of intangible genetic culture digitization based on AR technology lacks the research of quantitative design analysis and evaluation system. With the rapid development of artificial intelligence algorithms, the use of high-performance algorithms to solve the AR digitisation design analysis and testing problems has become one of the future directions for the application of AR technology in the development of intangible genetic culture. Considering that the digitisation of ICH is mainly to improve the dissemination of ICH as well as the development of its carriers to promote, that is, to adapt to the current low-carbon reform and tourism ICH promotion of digital applications [11].

Facing the problems existing in the current AR digital design of ICH as well as considering factors such as low-carbonisation tourism, this paper designs a design analysis and testing algorithm for assessing the AR digital design scheme. Around the consideration of low-carbon reform tourism ICH AR digital design process, combined with specific cases, through the

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analysis of AR digital design key technologies, using the restricted Boltzmann machine model [12] and heuristic optimization algorithms, designed a dragonfly algorithm [13] optimization restricted Boltzmann machine tourism ICH AR digital design test analysis algorithm.

This paper is composed of the following sections: Section II reviews the relevant research progress, reviews the existing AR and ICH digital research, and identifies gaps in technical details, performance analysis, and quantitative evaluation systems. In Section III: the research proposes an AR digitisation framework for Qinhuai Lantern Festival, which combines the dragonfly algorithm (DA) with the restricted Boltzmann machine (RBM) for optimisation. Key technologies such as AR interface design, data collection and model optimisation are analysed to improve the accuracy and efficiency of AR digitisation. In Section IV and Section V is the application part: through experiments comparing multiple algorithms, the DA-RBM model demonstrated superior performance, with a prediction accuracy of 93.5%, faster convergence and stronger testing capabilities. The paper concludes in Section VI by emphasizing the role of AR and intelligent algorithms in advancing cultural heritage protection and low-carbon tourism, demonstrating the effectiveness of the proposed DA-RBM model.

II. AR Digital Design Ideas

A. Background of the Study

In order to verify and analyse the effectiveness and superiority of the analysis algorithm of tourism intangible cultural heritage AR digitization design test analysis, this paper combines the case of intangible cultural heritage digitization of Qinhuai lanterns with the case of intangible cultural heritage digitization of Qinhuai lanterns by designing AR digitization scheme of intangible cultural heritage of intangible cultural heritage of Qinhuai lanterns, analyzing the key technologies, constructing the set of AR digitization design test indexes, and establishing the mapping relationship.

The Qinhuai Lantern Festival is one of China's traditional folk art forms, originating in the Qinhuai River Valley in Nanjing, with a long history and deep cultural heritage. It is not only known as "the first lantern festival in the world", but also famous for its grand scale and large number of participants. There are many types of lanterns, including lanterns, palace lanterns, and large lotus lanterns, many of which are used for children's games and adults' enjoyment, and have the nature of toys and handicrafts [14]. In 2008, Qinhuai lanterns were selected as part of the national intangible cultural heritage catalogue.

Qinhuai lanterns have the following characteristics [14]:

1) the shapes are mostly originated from nature;

2) the colours are characteristic of Jiangnan, mainly in the five basic tones of red, yellow, blue, green, and white;

3) they cover a variety of techniques such as paper-cutting, painting, carving, and papier-mâché.

The digital dissemination of Qinhuai lanterns is not only for the protection and inheritance of cultural heritage, but also for the diversification of culture to expand the means of dissemination, but also to inject new vitality into the traditional arts [15].

In order to improve the efficiency of digital design of Qinhuai lanterns and colours, this project obtains the digital design needs of Qinhuai lanterns and colours through questionnaires, field visits and user interviews. To summarize the digital design requirements of Qinhuai lanterns and colours, they include [16]:

- Improve the digital awareness of Qinhuai lanterns and colours AR;
- Diversify the digital functions of Qinhuai lanterns and colours AR;
- Enhance the digital stability of Qinhuai lanterns and colours AR;
- Improve the demand for digital social interaction and personalisation; and
- Increase the knowledge and fun, as display in Fig. 1.

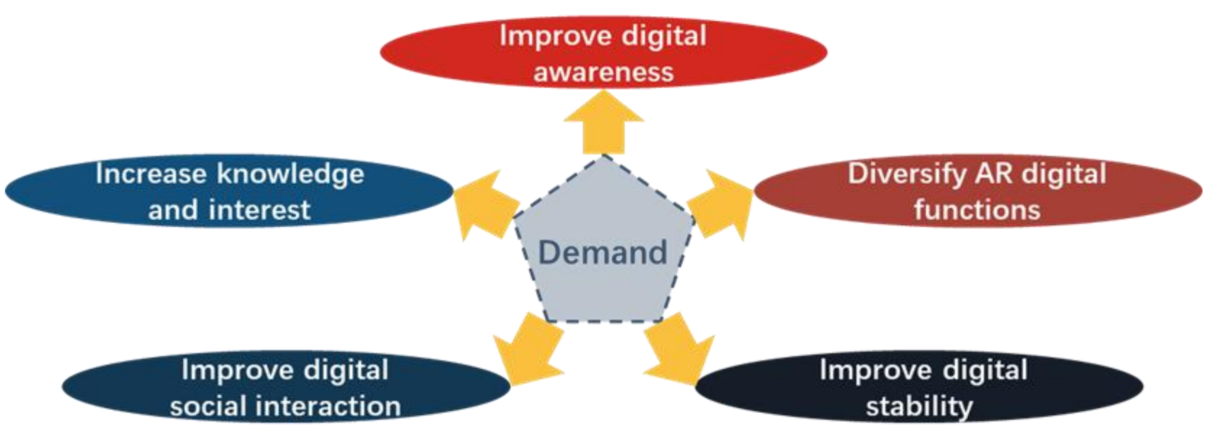


Fig. 1. Demand characterisation.

B. *Design Programme*

According to the digital design principles of real integrity, live scalability, and interactive experience [17], this paper designs a digital design and test and evaluation scheme for Qinhuai lantern AR that combines multiple technologies, as shown in Fig. 2.

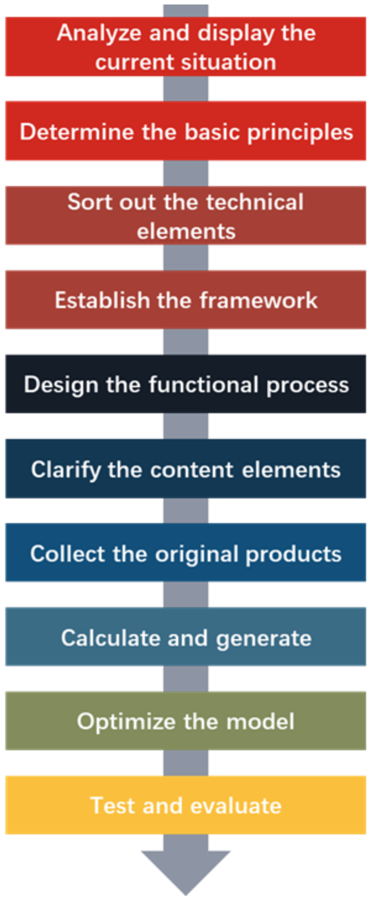


Fig. 2. General idea of the design.

From Fig. 2, the Qinhuai lantern AR digital design and testing and evaluation scheme is divided into three phases, such as pre-preparation, mid-phase, and post-phase, including the phases of analysing the current situation of the display, determining the basic principles, sorting out the technological elements, establishing the framework, designing the functional flow, clarifying the content elements, acquiring the original artefacts, generating the calculation, optimising the model, and testing and evaluating it [18].

In the Qinhuai lantern AR digital design and test and evaluation programme, based on the analysis of the current situation of the Qinhuai lantern display and its needs, the basic principles of the design are determined, and at the same time, the key technical elements of the digital display design are sorted out, and the digital display platform is structurally and functionally designed, the elements of the content are clarified, and the digital acquisition technology, storage technology, production technology, dissemination technology, and evaluation technology are used to complete the ICH. Digital display and effect analysis.

III. Analysis of Key Technologies for AR Digital Design

According to the flow of the design scheme, this section analyses the key technologies in terms of AR digital application interface design, data acquisition, digital model optimisation, digital design implementation and digital design testing, and the specific key technologies are shown in Fig. 3.

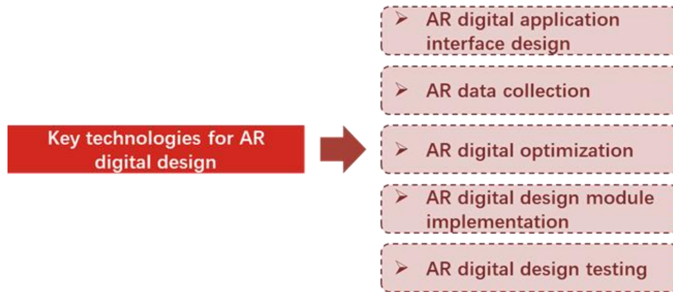


Fig. 3. Key technologies.

A. *AR Digital Application Interface Design Techniques*

In order to improve the satisfaction of the user experience, this paper divides the Qinhuai lantern AR application into three parts, such as discovery, AR display interface, and production techniques [19], and the specific information structure design is shown in Fig. 4. The discovery part is mainly used to provide users with information about the pavilions, activities, and works of the Qinhuai lanterns, and the display interface part is the entrance to the AR digital experience; the production techniques part is mainly used to provide users with the lantern production process.

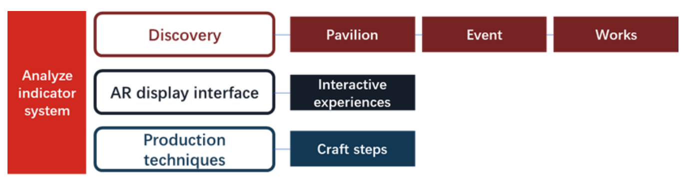


Fig. 4. AR digital information architecture design.

AR digital application interface design is divided into two phases, i.e., low-fidelity prototyping and high-fidelity prototyping [19]. Low-fidelity prototyping is generally at the initial stage of the design process and uses Figma design tools to quickly design concepts and interaction flows. High-fidelity prototype diagram design is based on low-fidelity prototype diagram design, with the help of Figma, illustrator and other design software, to carry out high-fidelity prototype diagram design and production. The high-fidelity prototype diagram design is generally designed from three aspects, such as discovery, AR display interface, and production techniques. For the AR digitisation of Qinhuai lanterns, the discovery page of this project is divided into three secondary pages, such as "Pavilion", "Activities" and "Works", as shown in Fig. 5; the AR display interface is mainly to serve the users with the AR display interface. The AR display interface mainly serves the AR interactive experience with users, as shown in Fig. 6; the production techniques are mainly selected from the perspective of universality and representativeness of the production steps of the lanterns and colours.

Fig. 5. Discovery page design.

Fig. 6. AR display interface.

B. AR Data Acquisition Techniques

The AR data acquisition technique is based on 3D scanning and modelling of Qinhuai lanterns through RealityCapture software (RC). The operation process based on RC software is shown in Fig. 7, including importing images, aligning images, calculating models, colouring, texturing, and exporting [20].

C. AR Digital Optimisation Techniques

In order to reduce the model size, reduce the rendering time, and maintain the original surface details and quality, the AR digital model optimisation method was used to process the model after AR data acquisition. The AR digital model optimisation method includes mesh simplification, material and texture optimisation, removal of hidden or redundant geometry, and merging of meshes and materials [21], as shown in Fig. 8.

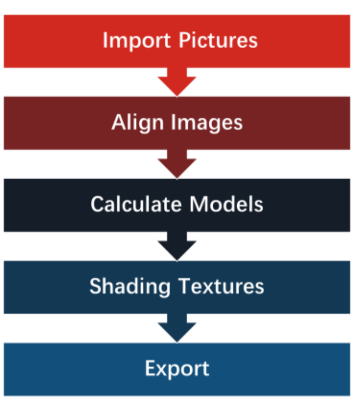


Fig. 7. RC software operation flow.

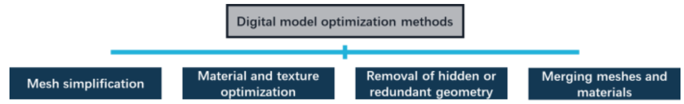


Fig. 8. AR digital optimisation method.

D. AR Digital Design Module Implementation Techniques

This project uses unity engine [22] for AR digital design module implementation.AR digital design module is implemented using SDK steps include importing Unity project, model shading, rendering model, target recognition and tracking.

E. AR Digital Design Testing Technology

AR digital design testing is mainly used for digital design performance analysis and effect evaluation [23].AR digital design testing technology tests and analyses the usability and stability of the AR digital design process by constructing and analysing the mapping relationship between AR digital design test index values and test evaluation levels, adopting certain fitting algorithms, and learning the training data, as shown in Fig. 9. This project uses an intelligent optimisation algorithm combined with a restricted Boltzmann machine.

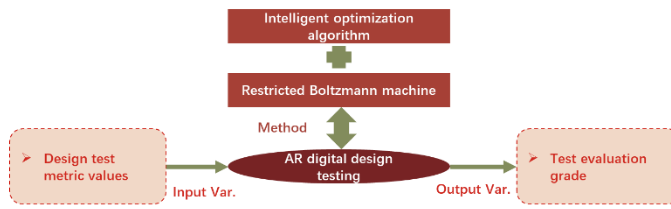


Fig. 9. AR digital design test methodology.

IV. AR Digital Design Testing

In order to analyse the AR digital quantification of Qinhuai lanterns and increase the accuracy of AR digital design test, this paper adopts the dragonfly algorithm to optimize the restricted Boltzmann mechanism to build the AR digital design test model.

A. AR Digital Design Test Models

1) AR digital design test metrics: In order to effectively analyse and assess the advantages and disadvantages of AR digital design solutions, based on the principles of systematic, objective, operable and other AR digital design test index selection, from the four aspects of the AR digital application interface A, acquisition B, model optimization C, design implementation D, to construct the AR digital design based on the discovery of A1, the AR display interface A2, the production techniques A3, aligning images B1, computing models B2, colouring B3, Texture B4, Mesh Simplification C1, Material and Texture Optimisation C2, Removal of Hidden or Redundant Geometry C3, Merging Mesh and Material C4, Model Colouring D1, Rendering Model D2, Target Recognition and Tracking D3, and other 14 test metrics sets [24], as shown in Fig. 10.

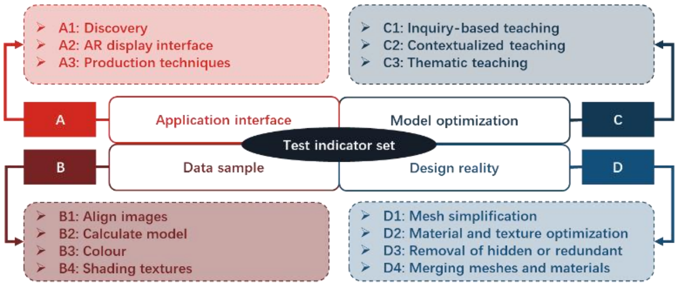


Fig. 10. Test indicator.

2) AR digital design test values and grades: In order to determine the quantitative AR digital design test assessment values and identify the test assessment levels, this paper divides the test assessment levels into six levels [24], and the specific relationship between each level and the corresponding test assessment value is shown in Table I.

TABLE I. CORRESPONDENCE BETWEEN TEST VALUE AND GRADE

No.	***Rank levels***	***Test scores***
1	Worse design	[0, 3]
2	Bad design	(3,6]
3	Fair design	(6,8]
4	Good design	(8, 10]
5	Better design	(10,12]
6	Great design	(12, 14]

3) Mapping relationships: For the Qinhuai lantern colours ICH, the AR digital design test model mainly constructs the mapping relationship between the AR digital design test indicators and the AR digital design test values as well as the grades, and the specific mapping calculation formula is as follows:

$$Y_{score} = f_{indicator-score}\left(X_{indicator}\right) \quad (1)$$

$$Y_{rank} = f_{ranklevel}\left(X_{indicator}\right) \quad (2)$$

Where $X_{indicator}$ denotes the AR digital design test metrics, $f_{indicator-score}$ denotes the mapping between the metrics and the test assessment values, Y_{score} denotes the AR digital design test values, $f_{ranklevel}$ denotes the mapping between the metrics and the test ratings, and Y_{rank} denotes the test ratings.

According to the principle of the AR digital design test model of Qinhuai lantern colour ICH, the mapping relationship between the AR digital design test indexes and the AR digital design test values as well as the grades is constructed as shown in Fig. 11.

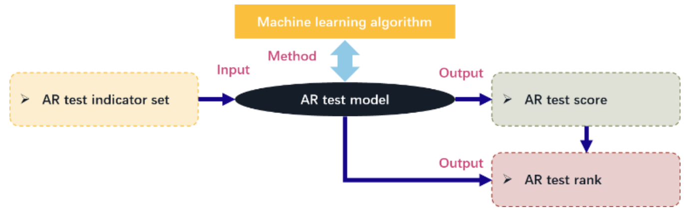


Fig. 11. AR digitisation test mapping relationship.

B. Intelligent Analysis Methods

Aiming at the problem of AR digital design testing of Qinhuai lanterns and ICH, this paper combines the constrained Boltzmann machine with the dragonfly algorithm, and proposes an intelligent analysis method for AR digital design testing based on the dragonfly algorithm to optimise the constrained Boltzmann machine.

1) Restricted boltzmann machines: Restricted Boltzmann Machine (RBM) [25] is an artificial neural network based on an energy model that consists of two layers of neurons: a visible layer and a hidden layer. The neurons between these two layers are fully connected, but there are no connections between neurons within the same layer. The RBM can be used for feature learning and generative model training, and is particularly adept at capturing high-level features of the data.

a) RBM probability distribution: RBM is a probability distribution model based on energy. Given the state vectors h and v, the current energy function of RBM is represented as follows:

$$E(v,h) = -a^T v - b^T h - h^T W v \quad (3)$$

where a and b denote the vector of bias coefficients and W denotes the weight matrix.

Define the probability distribution of the RBM in conjunction with the energy function:

$$P(v,h) = \frac{1}{Z} e^{-E(v,h)} \quad (4)$$

where Z is the normalisation factor.

$$Z = \sum_{v,h} e^{-E(v,h)} \quad (5)$$

According to the probability distribution, the conditional distribution is expressed as follows:

$$P(h|v) = \frac{P(h,v)}{P(v)} = \frac{1}{Z'} \prod_{j=1}^{n_h} \exp\left\{b_j^T h_j + h_j^T W_{j};v\right\} \quad (6)$$

where Z' is the new normalisation factor.

$$\frac{1}{Z'} = \frac{1}{P(v)} \frac{1}{Z} \exp\left\{a^T v\right\} \quad (7)$$

The sigmoid activation function is used in the RBM from the visible layer to the hidden layer:

$$P\left(v_j = 1 \middle| h\right) = sigmoid\left(a_j + W_{:,j}^T h\right) \tag{8}$$

b) RBM model loss function and optimisation: In order to solve for the parameters W , a and b , for m samples of the training set, the RBM generally uses a logarithmic loss function, i.e., it is expected to minimise the following equation:

$$L(W,a,b) = -\sum_{i=1}^{m} \ln\left(P\left(V^{(i)}\right)\right) \tag{9}$$

where $V^{(i)}$ denotes the ith particular training sample.

The gradient derivation results for the parameters W , a and b are as follows:

$$\frac{\partial\left(-\ln\left(P(V)\right)\right)}{\partial a_i} = \sum_v P(v) v_i - V_i \tag{10}$$

$$\frac{\partial\left(-\ln\left(P(V)\right)\right)}{\partial b_i} = \sum_v P(v) P\left(h_i = 1 \middle| v\right) - P\left(h_i = 1 \middle| V\right) \tag{11}$$

$$\frac{\partial\left(-\ln\left(P(V)\right)\right)}{\partial W_{ij}} = \sum_v P(v) P\left(h_i = 1 \middle| v\right) v_j - P\left(h_i = 1 \middle| V\right) V_j \tag{12}$$

RBM has a wide range of applications in a variety of machine learning tasks, including dimensionality reduction, feature learning, classification: for training classifiers, collaborative filtering, and generating models.

c) DA algorithm: Dragonfly Algorithm (DA) [26] is a novel intelligent optimisation algorithm proposed by Seyedali Mirjalili in 2016. The algorithm is inspired by the static and dynamic group behaviours of dragonflies in nature, in particular the collective intelligence they display in finding food and avoiding predators. The dragonfly algorithm is suitable for solving complex optimisation problems due to its high optimisation seeking capability and ease of implementation

The core of the dragonfly algorithm lies in modelling the group behaviour of dragonflies, including five behavioural styles such as separating, queuing, allying, searching for food and avoiding natural enemies. These behaviours are abstracted through mathematical models, forming the basic framework of the algorithm. In the algorithm, each individual dragonfly represents a potential solution, and the optimisation problem is explored and solved by simulating these behaviours.

- Separation behaviour: Neighbouring dragonflies are separated from each other and kept at a distance to avoid collisions:

$$S_i = -\sum_{j=1}^{N} \left(X - X_j\right) \tag{13}$$

where S_i denotes the value of the separation behaviour of the *i*th dragonfly, and X_j denotes the individual position of the jth dragonfly.

- Queuing behaviour: Individual dragonflies maintain the same speed as other dragonflies in their neighbourhood by controlling their speed and direction, allowing populations to migrate in the same direction:

$$A_i = \frac{\sum_{j=1}^{N} \Delta X_j}{N} \tag{14}$$

Where A_i denotes the amount of queuing behaviour, ΔX denotes individual speed and N denotes the number of dragonflies in the neighbourhood.

- Allied behaviour: Individual dragonflies and neighbouring conspecifics converge towards the centre of the surrounding group:

$$C_i = \frac{\sum_{j=1}^{N} X_j}{N} - X \tag{15}$$

where A_i denotes the amount of aligned behaviour.

- Food-seeking behaviour: Individual dragonflies seek out and approach food in order to survive:

$$F_i = X^+ - X \tag{16}$$

where F_i denotes the amount of foraging behaviour and X^+ denotes the location of food.

- Avoidance of natural enemy behaviour: Individual dragonflies have instinctive vigilance and behaviour away from natural enemies:

$$E_i = X^- + X \tag{17}$$

Where E_i denotes the amount of enemy avoidance behaviour and X^- denotes the location of natural enemies.

When there are other dragonflies in the neighbourhood of an individual dragonfly, the step vector is calculated as follows:

$$\Delta X_{t+1} = \left(sS_i + aA_i + cC_i + fF_i + eE_i\right) + \omega \Delta X_t \tag{18}$$

Where t denotes the current iteration number, s , a , c , f and e denote the separation, formation, focusing, foraging and enemy avoidance behavioural weights respectively, and ω denotes the inertia weights.

The updated formula for the position of the next generation of dragonfly individuals is:

$$X_{t+1} = X_t + \Delta X_{t+1} \tag{19}$$

When there are no other dragonflies in the neighbourhood of a dragonfly individual, the current dragonfly is unable to update its own position through the information of other individuals in the neighbourhood. In order to ensure that the algorithm better explores the search space, the dragonfly individual position is calculated as follows using the Lévy flight random wandering strategy:

$$X_{t+1} = X_t + Levy(d) \times X_t \tag{20}$$

$$Levy(d) = 0.01 \times \frac{r_1 \times \sigma}{|r_2|^{\frac{1}{\beta}}} \tag{21}$$

$$\sigma = \left(\frac{\Gamma(1+\beta) \cdot \sin \frac{\pi\beta}{2}}{\Gamma\left(\frac{1+\beta}{2}\right) \cdot \beta \cdot 2\left(\frac{\beta-1}{2}\right)} \right)^{\frac{1}{\beta}} \tag{22}$$

where $Levy(d)$ denotes the Levy flight strategy and $\Gamma(x) = (x-1)!$.

The formula for calculating the radius of the dragonfly neighbourhood is as follows:

$$r = \frac{ub - lb}{4} + 2(ub - lb)\frac{t}{t_{\max}} \tag{23}$$

Where ub and lb denote the upper and lower limits of the search space, t and $t_{\max}$ are the current iteration number and the maximum iteration number. The radius of the dragonfly neighbourhood increases with the number of iterations. When the number of iterations increases for a certain number of times, all dragonflies become individuals in the neighbourhood, updating their positions and step sizes through the information of all other dragonflies, which will eventually converge.

d) Constrained Boltzmann machine models incorporating DA algorithms: In order to increase the accuracy of the testing algorithm, this paper uses the dragonfly algorithm to optimise the RBM model, i.e., the dragonfly algorithm is used to find a set of RBM parameters to minimise the testing error.The decision variables of the DA-RBM algorithm are the parameters W , a , and b , and the RMSE value is used as the fitness evaluation function of the dragonfly algorithm:

$$RMSE = \sqrt{\frac{1}{M}\sum_{i=1}^{M}(\hat{y}_i - y_i)^2} \tag{24}$$

Where, x is the data sample, c_i denotes the i^{th} clustering centre and d denotes the dimension of the data sample.

The flow of the DA algorithm to optimise the RBM method is displayed in Fig.12 with the following steps:

- Step 1: Initialise parameters, including population size, maximum number of iterations, etc;
- Step 2: Based on the structural parameters of the RBM model, generate an initial population, i.e., dragonfly individuals randomly distributed in the search space;
- Step 3: Assess the fitness of each individual dragonfly, i.e. the quality of its problem solving;
- Step 4: Determine whether there are other individuals in the dragonfly's neighbourhood, if so, update the individual's position by using separation, queuing, alliance, food searching and natural enemy avoidance behaviours, otherwise update the individual's position by using the Levy flight strategy;
- Step 5: Repeat the above steps until the maximum number of iterations, output the optimal RBM model structure parameters, and construct the RBM model based on the DA algorithm.

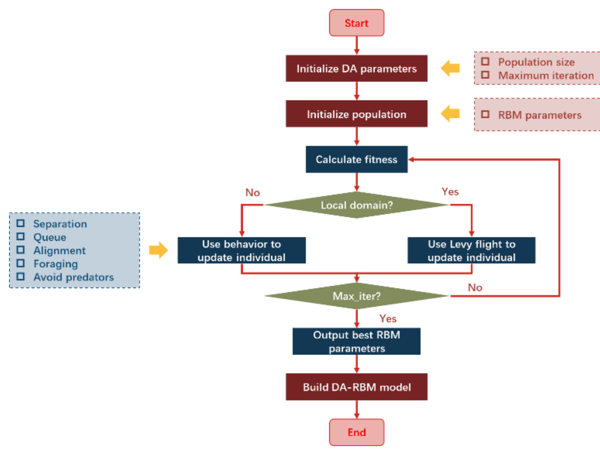


Fig. 12. Flowchart of DA-RBM algorithm.

e) Design test intelligent analysis model construction process: In order to construct an intelligent analysis model based on the AR digital design test of Qinhuai lanterns and colours, this paper adopts the DA-RBM model, by analysing the AR digital design test indexes and test values, taking the parameters of RBM W , a and b as the optimization variables, and taking the RMSE value as the fitness value function, and using DA algorithm optimization strategy to search for the optimal parameters of RBM W^* , a^* and b^* . The principle of the application of the DA-RBM model and the structure of the framework are shown in Fig. 13.

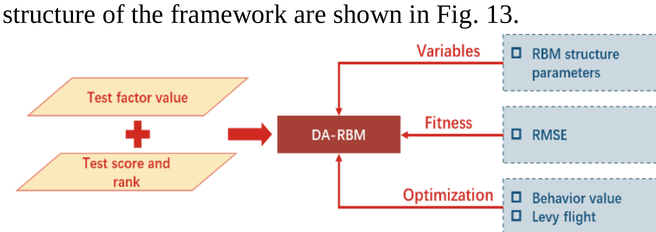


Fig. 13. DA-RBM application analysis.

According to the application of DA-RBM model in the AR digitisation problem of Qinhuai lantern colour low-carbon tourism ICH, the specific flow of the design test intelligent analysis method based on DA-RBM model is shown in Fig.14. As can be seen from Fig. 14, by analysing the key technology of AR digitization of Qinhuai lanterns and low-carbon tourism ICH, determining the AR digitization design test indexes, test scores, and grades, and after the data preprocessing technology, obtaining the training and testing sample set, combining with the intelligent optimization algorithm proposed in this paper to improve the machine learning algorithm, to achieve the construction and optimization of AR digitization design test model of AR digitization of ICH of low-carbon tourism of Qinhuai lanterns and colours.

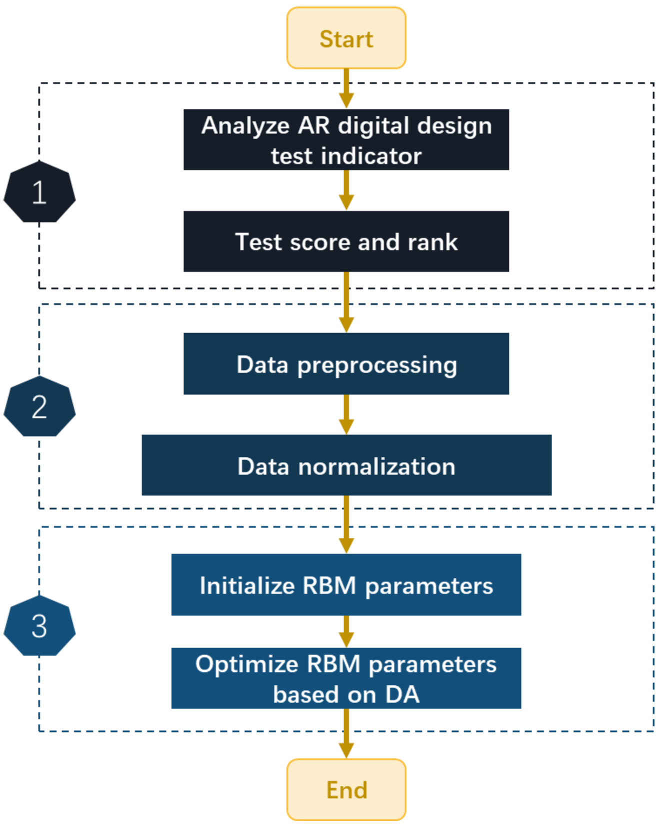


Fig. 14. Building intelligent analysis model for design test.

V. Analysis of Test Results

A. Test Environmental Setup

The experimental simulation environment is Windows 10, CPU is 2.80GHz, 8GB RAM. RealityCapture software is used for digitisation of Qinhuai lanterns, Vuforia SDK is used for functional implementation of AR, and Python 3.7 is used as the programming language for ICH AR digital design and testing algorithm.

B. Contrast Algorithm Parameter Settings

In order to verify the feasibility and efficiency of the ICH AR digital design and testing algorithms proposed in this paper, this paper takes the data collected during the AR digital design process of Qinhuai lanterns and colours as the analysis data, and six design testing algorithms are selected for comparison, as shown in Table II.

TABLE II. Comparison Algorithm Parameter Settings

Projects	***Parameter settings***
RBM	The number of hidden layer nodes is 150
PSO-RBM [27]	V_{max}=30, V_{min}=-30, r=0.5
GSA-RBM [28]	Alpha is 20, G0 is 100, Rnorm=2, Rpower=1
TLBO-RBM [29]	Tr=round(1+rand)
GWO-RBM [30]	a decreases linearly from 2 to 0
DA-RBM	Inertia weights are [0.4,0.9], separation, queuing, alliance, foraging, and enemy avoidance are 0.1, 0.1, 0.7, 1, and 1 respectively

As can be seen from Table II, the comparison algorithm parameters are mainly divided into two categories. For the RBM model parameters, the number of hidden layer nodes is set to 150; for the intelligent optimisation algorithm parameters, the maximum number of iterations is set to 100 and the population size is 50.

C. Analysis of AR Digital Realisation

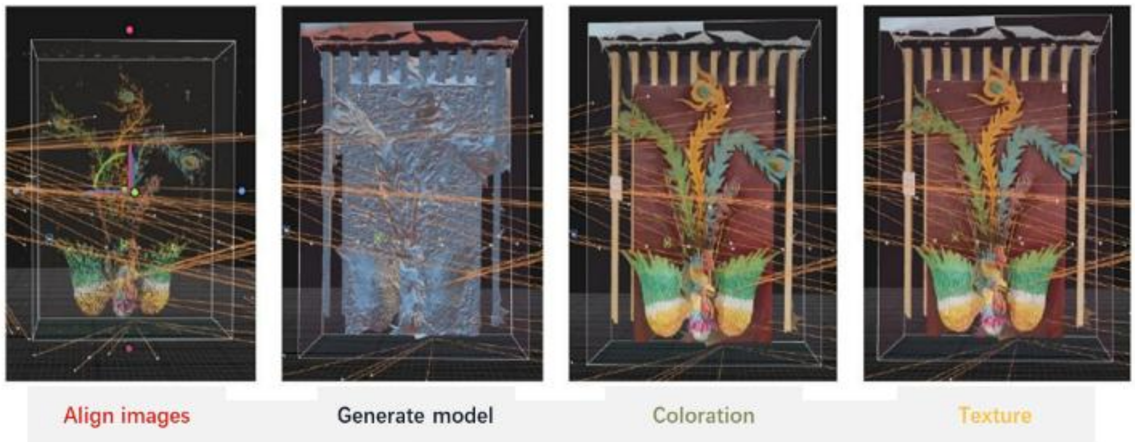
In order to verify the effectiveness of the AR digitisation design method, this paper adopts RealityCapture software and Vuforia SDK to implement the AR digitisation of Qinhuai lanterns and colours, and the specific analysis results are shown in Fig. 15 and Fig. 16.

From Fig. 15, the AR digital acquisition of Qinhuai lanterns is done through the process of aligning images, generating models, colouring and texturing to get the AR digital preliminary model.

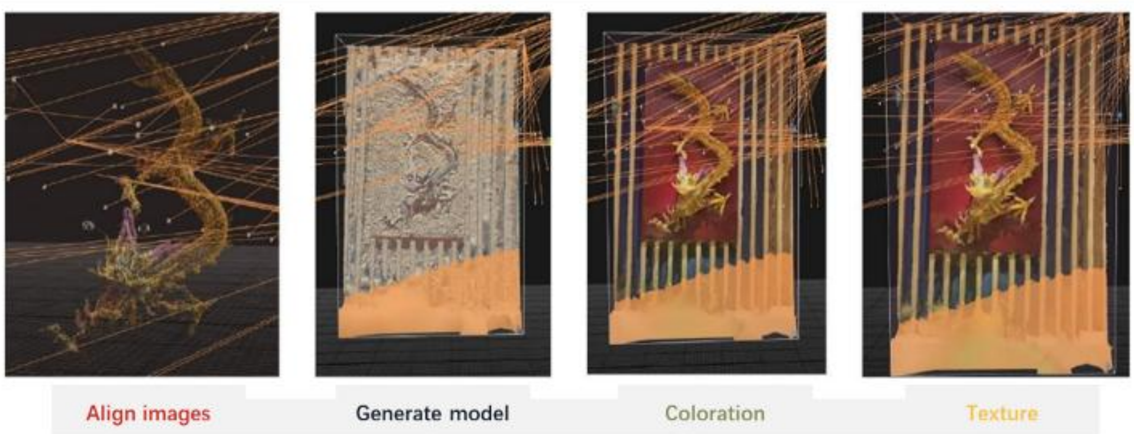
D. Test Performance Analysis

In order to validate the feasibility and effectiveness of the AR digitisation design test method based on the DA-RBM model, this paper compares the performance of the RBM, PSO-RBM, GSA-RBM, TLBO-RBM, GWO-RBM, and DA-RBM methods by using Qinhuai Colourful Lanterns AR digitisation process dataset.

From Fig. 16, we can see that the RBM optimisation based on the DA algorithm has a higher convergence accuracy than the other algorithms and has a better convergence speed than the other algorithms; the DA-RBM starts to converge at 20 iterations and converges to near 0.



(a) Intentions of the digital acquisition process for the Phoenix Lights model



(b) Intentions of the digital capture process for the dragon lantern model

Fig. 15. Digital acquisition process of Qinhuai lantern colours.

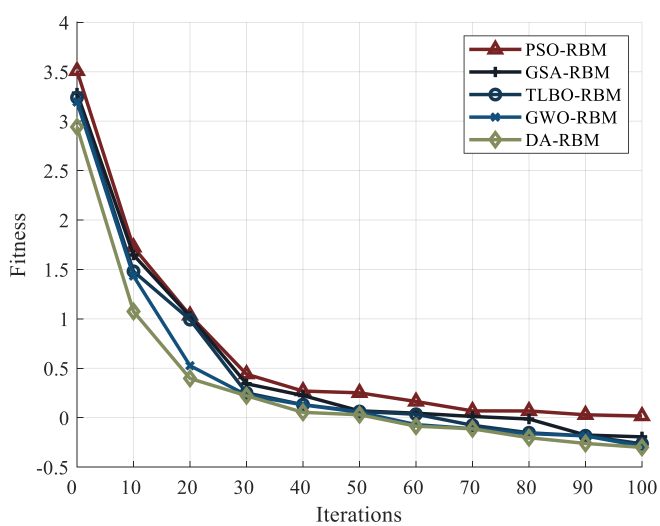


Fig. 16. AR digital design test method based on intelligent optimisation algorithm.

The test prediction scores for the RBM, PSO-RBM, GSA-RBM, TLBO-RBM, GWO-RBM, and DA-RBM methods, as well as the test rating results, are given in Figure 16. As can be seen from Fig. 17, the test prediction scores of the AR digital design test algorithm based on the DA-RBM model are closest to the true scores, and the test prediction errors are less than those of RBM, PSO-RBM, GSA-RBM, TLBO-RBM, and GWO-RBM.

The statistical results of RBM, PSO-RBM, GSA-RBM, TLBO-RBM, GWO-RBM, and DA-RBM method tests are given in Table III. In terms of RMSE, the prediction error of the DA-RBM-based AR digital design testing algorithm is the smallest, reaching 0.0178; in terms of accuracy, the test score prediction accuracy of the DA-RBM-based AR digital design testing algorithm is the smallest, reaching 93.5%; in terms of optimisation convergence time, the DA-RBM-based AR digital design testing algorithm has the shortest optimisation convergence time of is 4.40s; in terms of testing time, the DA-RBM-based AR digital design testing algorithm has the smallest test sample prediction time of 0.48s.

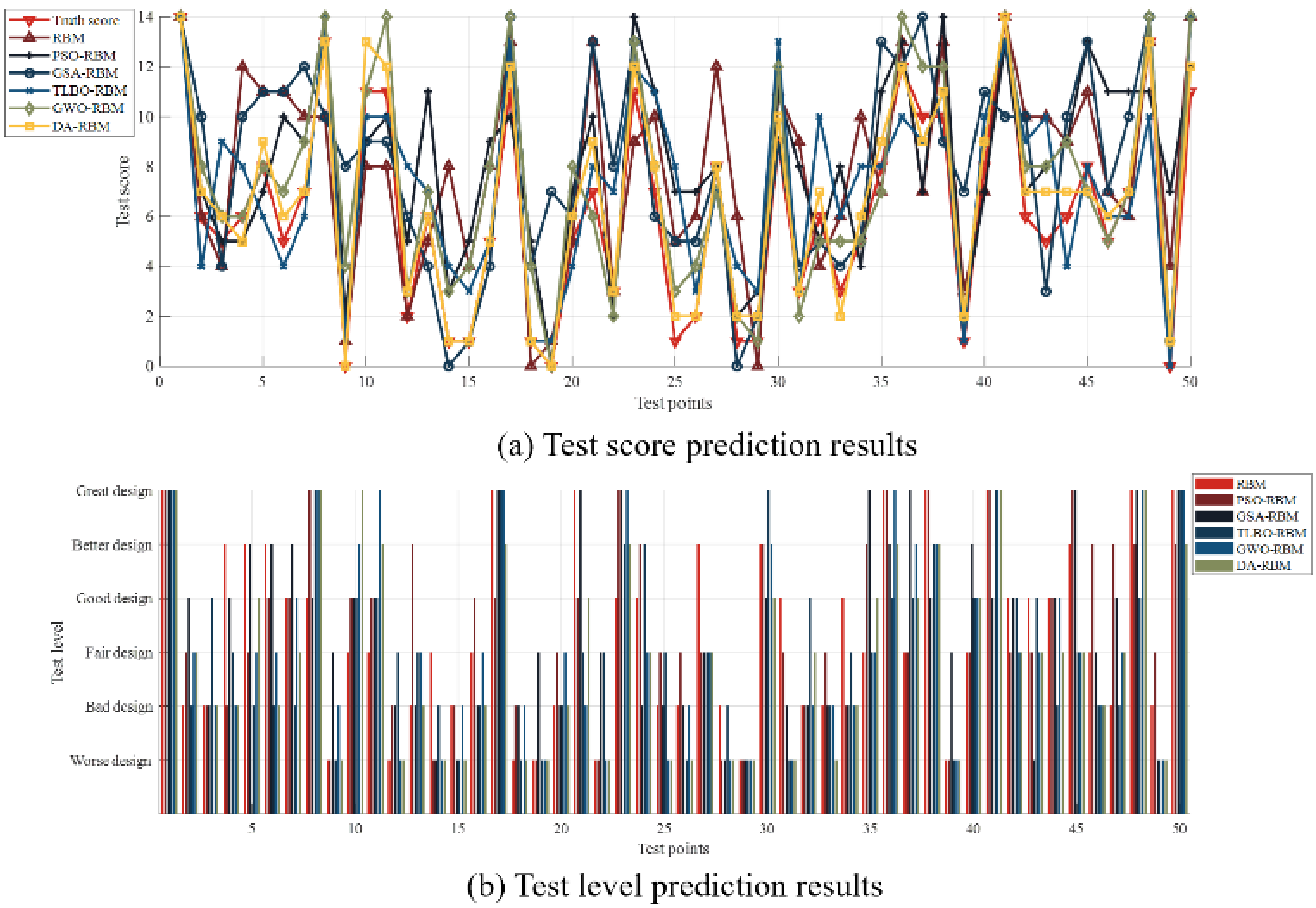


Fig. 17. Predicted performance results of test methods.

TABLE III. COMPARISON OF DESIGN TEST ALGORITHM PERFORMANCE

Arithmetic	*RMSE*	*Precision/%*	*Optimisation time/s*	*Test time/s*
RBM	0.0698	85.92	4.88	0.98
PSO-RBM	0.0549	88.76	5.83	0.87
GSA-RBM	0.0671	86.21	7.76	0.95
TLBO-RBM	0.0433	90.88	4.56	0.56
GWO-RBM	0.0368	90.35	5.45	0.59
DA-RBM	0.0178	93.50	4.40	0.48

VI. Conclusion

This study demonstrates that integrating augmented reality (AR) with advanced data-driven algorithms significantly enhances the digital design and testing process for intangible cultural heritage (ICH), particularly in the context of low-carbon tourism. By employing the Dragonfly Algorithm (DA) optimized Restricted Boltzmann Machine (RBM) model, we successfully improved the accuracy, efficiency, and robustness of AR digitization for the Qinhuai Lantern Festival.

The proposed AR digital design testing algorithm outperformed other methods, achieving a test score prediction accuracy of 93.5%. This superior performance highlights the model's capacity to process and analyze large datasets with greater speed and precision, making it an effective solution for assessing AR digital designs in the preservation and promotion of ICH.

By focusing on both cultural preservation and eco-friendly tourism, this method not only strengthens the protection of heritage but also contributes to sustainable tourism development. As AR technology continues to evolve, integrating intelligent optimization algorithms like DA will play a crucial role in shaping the future of digital cultural communication and heritage conservation.

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