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Innovative Protection and Inheritance of Cultural Heritage in the Digital Age

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Abstract. This article aims to explore the application and innovative practice of digital technology, especially CAD (Computer Aided Design) and big data, in the field of cultural heritage (CH) protection and inheritance. By constructing the technical framework of the integration of CAD and big data, this article proposes a new CH protection mode. Methodologically, this study combined the 3D modelling ability of CAD, big data analysis algorithm VR, and other advanced technologies and carried out a comprehensive digital restoration, virtual exhibition, and intelligent pre-alarm system development for CH. The results show that the integration of CAD and big data significantly improves the efficiency of CH protection. Digital repair technology can accurately simulate and repair the disease of CH, while virtual exhibitions and interactive experiences greatly enhance the public participation and social influence of CH. At the same time, the establishment of an intelligent pre-alarm system provides strong support for real-time monitoring and risk management of CH. The conclusion drawn is that integrating CAD with big data offers fresh perspectives and approaches for safeguarding and perpetuating CH. This integration not only aids in its enduring preservation and efficient use but also fosters advancements and applications in related technological fields.

Keywords: Digital Age; CAD; Big Data; Cultural Heritage Protection; Innovation Practice
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1 INTRODUCTION

With the diversified development of the times, protecting and inheriting intangible cultural heritage has become a global issue. As an important component of human culture, intangible cultural heritage represents the cultural diversity and creativity of different ethnic groups, regions, and communities [1]. These intangible cultural heritage skills not only have cultural value but also economic value. However, due to the impact of modernization and talent loss, the intangible cultural heritage skills in old brands are facing the risk of extinction. We also need to strengthen protection. The use of digital means is one of the ways to protect and inherit intangible cultural heritage better [2]. By using digital technology to record, preserve, and disseminate intangible cultural heritage, it can be more widely disseminated and better integrated into contemporary society. However, due to various reasons, the inheritance and protection of intangible cultural heritage face many challenges [3]. The intangible cultural heritage skills of time-honoured brands are an important component of intangible cultural heritage [4]. As a digital communication method, digital picture books can present intangible cultural heritage in a clear and intuitive way to readers through interactive narrative, visual design, sound design, and interactive design, becoming a new way and means of disseminating intangible cultural heritage [5]. The absorption and utilization of intangible cultural heritage and time-honoured brand resources by digital picture books can not only provide rich cultural connotations and historical origins for stories but also provide readers with deeper cultural experiences and cognition [6]. Secondly, historical stories and folklore related to time-honored intangible cultural heritage brands should be collected, and used as the background for digital picture books. For example, by introducing the historical origins, inheritance methods, craft techniques, cultural connotations, and other aspects of intangible cultural heritage skills, readers can gain a deeper understanding of the unique charm and cultural value of these intangible cultural heritage skills. Integrating the intangible cultural heritage skills of these time-honoured brands into the story and designing digital picture books, allows readers to not only understand the time-honoured brands but also further explore the intangible cultural heritage resources within them. Design it as the theme of digital picture books, allowing readers to understand the cultural value and spiritual connotation of these intangible cultural heritage skills. The construction of digital picture book story themes can absorb and utilize intangible cultural heritage and time-honoured brand resources through the following aspects. The intangible cultural heritage projects included in the time-honoured brands of intangible cultural heritage mainly involve the excavation and development of intangible cultural heritage techniques [7].

Through the analysis of massive cultural heritage data, the historical context, cultural significance, and social value behind cultural relics can be revealed, providing strong support for academic research, education popularization, and cultural inheritance. The combination of IoT technology and big data analysis provides the possibility for real-time monitoring and preventive protection of cultural heritage [8]. Meanwhile, with the help of technologies such as virtual reality (VR) and augmented reality (AR), people can immerse themselves in the charm of cultural heritage, promoting the widespread dissemination and inheritance of culture.

In the virtual Ganjali Khan project, 3D scanning technology was first used to collect high-precision 3D data of the complex. Subsequently, big data processing and analysis techniques were applied to these massive amounts of data, filtering key information through algorithms. This intelligent restoration simulation based on big data not only improves the accuracy and efficiency of restoration work but also reduces trial and error costs, providing more scientific and reasonable decision support for cultural heritage protection [9]. These data not only cover the external form of the building, but also delve into the internal structure, decorative details, and even material textures, forming a huge dataset. Indicators such as structural stability assessment and historical restoration records provide a scientific basis for subsequent digital reconstruction and protection strategy formulation [10]. The precise matching and recommendation algorithms of big data can also provide personalized tour routes and interactive experiences based on users' interests and behavioural habits, greatly enriching the forms and connotations of cultural dissemination.

This research mainly focuses on the application of CAD and big data in the protection and inheritance of CH. The specific research scope includes the digital collection of CH, 3D modeling, big data analysis, and the innovative practice of their integration. The research goal is to put forward an innovative scheme of CH protection and inheritance based on CAD and big data through in-depth analysis of the principles and methods of CAD and big data technology and their application status in the CH field in order to provide a new scheme to solve the current problems faced by CH protection.

The chapters of this article are arranged in a compact and orderly way. Firstly, the research background, purpose, and significance are expounded in the introduction. Then, in the second to fifth sections, the technical framework of integration of CAD and big data in CH protection and inheritance and innovative practice cases (including digital restoration, virtual exhibition and interactive experience, and intelligent pre-alarm system) are discussed in detail. The sixth section analyzes the challenges and countermeasures, and the seventh section summarizes the research results and looks forward to the future research direction and practical significance.

The innovation of this article is mainly reflected in:

(1) A technical framework for the integration of CAD and big data in the field of CH protection is proposed, which realizes the cross-border application of technology.

(2) Through innovative practices such as digital restoration and virtual exhibition, the accuracy of CH protection and public participation have been improved.

(3) An intelligent pre-alarm system based on big data is built, which provides a new means for the safety management of CH.

(4) Interdisciplinary integration of knowledge in history, art, computer science and other fields has promoted the in-depth development of CH protection research.

2 RELATED WORK

The collective memory project aims to establish and maintain the historical identity of social communities by recording, protecting, and disseminating cultural heritage. The application of big data technology makes this process more efficient, comprehensive, and in-depth. As an important institution for protecting and inheriting cultural heritage, RUSI's digital transformation is an inevitable choice in line with the trends of the times. Wang et al. [11] introduced big data technology and RUSI not only achieved digital recording and archiving of cultural relics in its collection, but also established a cultural relic information management system based on big data, realizing rapid retrieval, intelligent analysis, and visual display of cultural relic information. Designing engaging courses that encourage students to participate in the protection of cultural heritage records, not only cultivates students' professional skills and innovation abilities but also inspires their interest and sense of responsibility for the protection and inheritance of cultural heritage. Big data can reveal the historical background, cultural connections, and social changes hidden behind the data, providing rich materials and a scientific basis for the construction of collective memory. Ye [12] collects, organizes, and analyzes a large amount of historical data, cultural relic information, oral history, and other multi-source data. The student project organized by RUSI is a vivid practice of big data in the field of cultural heritage education. In the process of project implementation, the application of big data technology provides students with rich data resources and analysis tools, enabling them to have a deeper understanding of the historical value and cultural connotation of cultural heritage, and thus design more innovative and practical solutions. In addition, RUSI also utilizes big data platforms to establish extensive partnerships with domestic and foreign cultural heritage institutions, jointly promoting the digital protection and inheritance of cultural heritage.

The introduction of big data has made the design process more data-driven and intelligent, promoting the deep integration of design and manufacturing. Through data analysis, You [13] can more accurately grasp market demand, and design bamboo weaving products that conform to traditional aesthetics and modern lifestyles, thereby enhancing the market competitiveness of the products and promoting the sustainable development of the industry. In response to the lack of division of labour between design and manufacturing in bamboo basket production, Zhou et al. [14] developed specialized design assistance tools using big data and artificial intelligence technology. This innovative practice breaks down the communication barriers between designers and manufacturers in traditional craftsmanship, allowing designers to directly explore and express complex weaving structures in a digital environment without relying on tedious sample production processes. These tools can not only achieve digital modelling from basic structures to freely woven structures but also automatically map from 2D design to 3D woven structures through algorithm optimization. Meanwhile, big data can also help identify and optimize bottleneck links in the production process, improving production efficiency. By predicting and analyzing market demand, Zhou et al. [15] can arrange production plans reasonably, reduce inventory backlog, and lower production costs. With the support of big data, we can collect and analyze user preferences, usage habits, and feedback data on bamboo weaving products, providing designers with accurate market insights. This not only stimulates the creativity of designers, but also promotes personalized customization services for products. The application of big data in supply chain management makes the procurement of raw materials, production and processing, and logistics distribution in the bamboo weaving process more transparent and efficient.

At present, there is relatively little research on the combination of CAD and big data for CH protection and inheritance. This study summarizes the previous research results and experiences and provides the theoretical basis and reference for the development of this study. CAD technology is a computer-aided design technology, which has the advantages of high precision, high efficiency and easy modification. In CH protection, CAD technology is mainly used in digital acquisition, 3D modelling and virtual repair of CH. Through CAD technology, accurate measurement and modelling of CH can be realized, which provides accurate data support for subsequent protection and restoration work. Big data technology refers to the technology of processing data sets that are difficult to manage and process by conventional means through specific technologies. In CH protection, big data technology is mainly used to collect, store, analyze, and mine massive data related to CH, so as to reveal the historical, cultural, and social value of CH. Digital acquisition is the first step in CH's digital protection. By means of laser scanning and photogrammetry, high-precision digital images and three-dimensional point cloud data of CH can be obtained. Then, these data are processed by CAD technology to construct a three-dimensional model of CH. In this process, key algorithms such as point cloud stitching and surface reconstruction need to be applied to ensure the authenticity of the model.

3 INNOVATIVE PRACTICE OF BIG DATA IN CH PROTECTION AND INHERITANCE

3.1 CH Big Data Platform Construction

The construction of the CH big data platform is the foundation of the innovative practice of big data technology in CH protection and inheritance. The platform aims to integrate CH-related data from different channels and formats, including but not limited to basic information, historical evolution, protection status, tourist visits, and environmental monitoring data of CH. By building a unified data storage, processing, and analysis platform, the comprehensive and efficient management of CH data can be realized, which provides a basis for subsequent data analysis and decision support.

In the process of platform construction, this article mainly solves a series of technical problems such as data collection, data cleaning, data storage, and data security. Especially in data collection, this article makes full use of the Internet of Things, sensors, drones, and other modern technical means to realize real-time monitoring and data collection of CH, as shown in Figure 1.
At the same time, encryption technology and access control are also adopted to ensure the security of data during transmission and storage.

3.2 Application of Big Data Analysis Algorithm

(1) Save state monitoring

Using big data analysis technology, the preservation status of CH can be monitored and evaluated in real time. By collecting environmental monitoring data of CH (such as temperature, humidity, illumination, etc.), as well as related data such as the number of visitors and the implementation of protective measures, a monitoring model of the CH preservation state can be constructed [14]. The model can analyze data in real time, find potential risks and problems, and issue pre-alarm in time, which provides a scientific basis for the protection of CH.

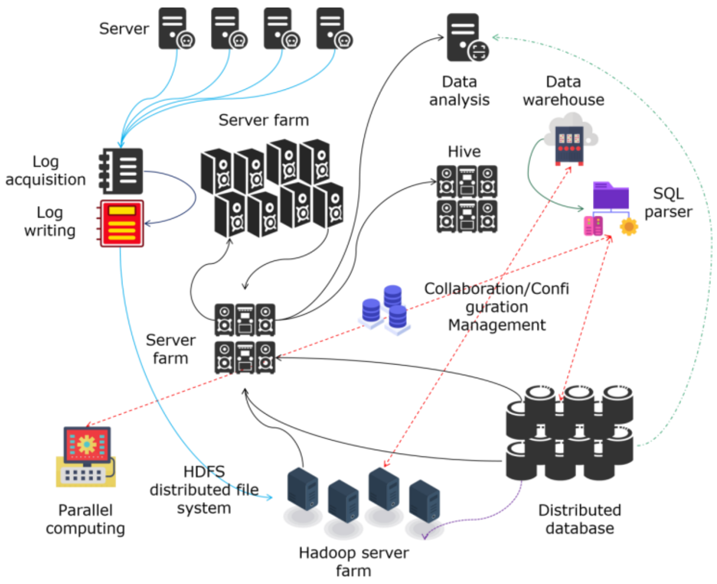

Figure 1: Data acquisition framework.

(2) Trend prediction and decision support

Big data analysis technology can also be used for trend prediction and decision support in CH protection decisions. By mining the historical data in the process of CH protection, the prediction model of key indicators such as disease development and protection effects can be constructed. The model can predict the protection status of CH in the future and provide the scientific basis for making long-term protection planning.

Tourist traffic analysis is an important application of big data in CH protection. By collecting and analyzing the data on tourists' visits, stay time, tour paths, etc., we can understand the preferences and needs of tourists and provide a basis for formulating reasonable tourist management strategies. Taking a scenic spot in CH as an example, by introducing big data analysis technology, the scenic spot successfully identified that weekends and holidays are the peak hours for tourists to visit, and the tourist flow is mainly concentrated in a few popular scenic spots. In response to this problem, scenic spot managers responded quickly and adopted a series of targeted measures. First of all, in order to alleviate the pressure of tourists during peak hours, the scenic spot has implemented current-limiting measures, effectively controlling the number of tourists entering the park through the reservation system and time-sharing admission and avoiding the potential safety hazards and the decline of the tour experience caused by overcrowding. Secondly, in order to improve the depth of tourists' visits, the scenic spot has increased the number and quality of tour guide services and explanation boards, as shown in Figure 2.

The tour guide service not only provides professional explanations and guidance for tourists but also helps them better understand the historical background and cultural connotations of CH. The carefully designed explanatory signs are like silent tour guides, always answering tourists' questions and guiding them to discover more hidden cultural treasures. The implementation of these measures not only effectively enhances tourists' travel experience but also strengthens their awareness and respect for CH protection. More importantly, through continuous analysis and feedback of big data, scenic area managers can continuously optimize their management strategies and achieve a virtuous cycle between CH protection and tourism development. Market research is another important application of big data in CH protection. By collecting and analyzing market data on CH-related products (such as sales volume, prices, user assessments, etc.), we can understand the market demand and competitive situation and provide decision support for the activation and sustainable development of CH.

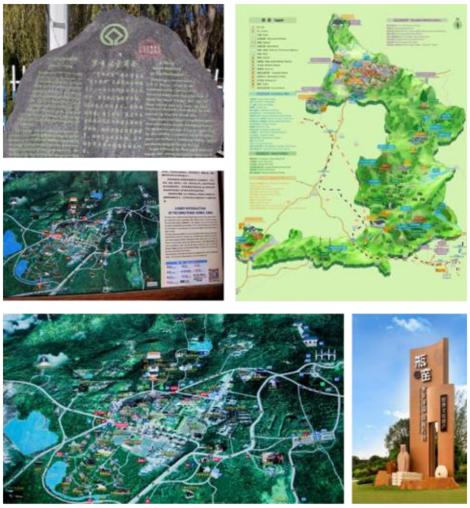

Figure 2: Example of tour guide service and explanation board.

Taking a certain CH area as an example, through big data analysis, it was found that tourists showed a strong interest in cultural products with distinct local characteristics. In order to seize this market opportunity, the area has taken active action and developed a series of unique cultural and creative products based on its CH resources, as shown in Figure 3.

Figure 3: Cultural and creative products.

These products not only incorporate local cultural elements and historical stories but also pay attention to innovation and practicality, meeting the multiple needs of tourists for souvenirs, gifts and cultural experiences.

On the basis of product development, the area has also increased its marketing efforts. Through big data analysis, they accurately positioned the target consumer groups, formulated targeted marketing strategies, and made extensive publicity through social media, online platforms and other channels. These efforts not only enhanced the popularity and influence of CH but also promoted the sales of cultural and creative products, bringing remarkable economic benefits to CH, as shown in Figure 4.

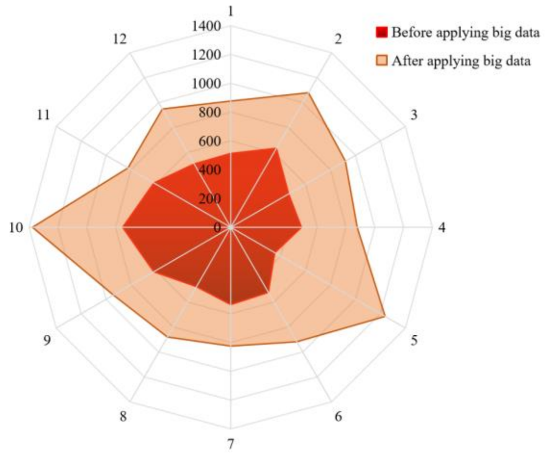

Figure 4: Economic benefits.

The economic benefits and social benefits realized in this process complement each other. Through market research and big data analysis, CH can meet the market demand more accurately and enhance the satisfaction and loyalty of tourists. At the same time, the sales of cultural and creative products have further promoted the spread and inheritance of CH and enhanced the public's understanding and respect for CH. This virtuous cycle not only provides continuous power for the activation and utilization of CH, but also lays a solid foundation for the long-term development of CH protection.

4 INNOVATIVE PRACTICE OF CAD AND BIG DATA FUSION

4.1 Fusion Technology Framework

In the protection and inheritance of CH, the innovative practice of integration of CAD and big data needs to build a comprehensive technical framework to give full play to their advantages in data processing, analysis, modelling and decision support. The framework mainly includes the following key components:

(1) Data collection and integration: Using the Internet of Things, remote sensing, unmanned aerial vehicles and other technical means, combined with the accurate measurement ability of CAD, comprehensively collect all kinds of data of CH, including physical state, environmental parameters, historical changes, etc. These data are then integrated into the big data platform, providing a basis for subsequent analysis.

(2) Big data processing and analysis: using big data processing technologies and algorithms, the collected massive data are cleaned, transformed, mined and analyzed to reveal the preservation status, changing trend and potential risks of CH.

Noise removal: Assuming that D is the original data set, D_{clean} is the cleaned data set, and N is the noise data set, then the cleaning process can be expressed as:

$$D_{\text{clean}} = D - N \tag{1}$$

Redundant data removal: A similarity measure function S is used to identify and remove redundant data, such as cosine similarity:

$$S\left(x,y\right) = \frac{x \cdot y}{\|x\|\|y\|} \tag{2}$$

Where x and y are two data points. If $S\left(x,y\right)$ is greater than a certain threshold θ, x and y are considered redundant.

Data formatting: converting data into a unified format, which can be expressed by a conversion function T:

$$D_{\text{formatted}} = T\left(D_{\text{clean}}\right) \tag{3}$$

The original data is cleaned to remove noise and redundancy and then converted into an easy-to-analyze format, and then these data are integrated into the big data platform to provide a basis for subsequent analysis.

In this article, the k-means algorithm is used to cluster the changing trend of CH:

$$c_{\text{i}} = \arg\min_{c} \sum_{x \in S_i} \|x - c\|^2 \tag{4}$$

Where c_{i} is the i cluster centre and S_{i} is the data point set belonging to the i cluster?

Time series prediction: using autoregressive integral moving average model to predict the changing trend of CH:

$$\left(1-B\right)^{d} X_t = c + \left(1-\varnothing_1 B - \ldots - \varnothing_p B^p\right)\left(1-B\right)^{d} \in_t \tag{5}$$

Where B is the backward shift operator, d is the difference degree, c is the constant term, $\varnothing_p$ is the autoregressive coefficient, and $\in_t$ is the white noise. This analysis process can not only reveal the current preservation status of CH but also describe its changing trend with time and predict its future development direction. Through in-depth analysis, the potential risks faced by CH can be identified, thus providing forward-looking guidance for protection work.

(3) CAD 3D modelling and visualization: Based on the results of big data analysis, this article collects, processes and analyzes massive CH-related data, including size, material, colour and historical change information, which lays a solid foundation for building high-precision 3D models. Using voxel representation to construct a three-dimensional model M:

$$M = \bigcup_{v \in V} v \tag{6}$$

Where V is the set of voxels that make up the model? Calculate the pixel colour L_o using the rendering equation:

$$L_o\left(p,\omega_o\right) = L_e\left(p,\omega_o\right) + \int_{\Omega} f_r\left(p,\omega_i,\omega_o\right) L_i\left(p,\omega_i\right) \cos\theta_i d\omega_i \tag{7}$$

Where L_e is self-luminescence, f_r is bidirectional reflection distribution function, L_i is incident light, and θ_i is incident angle.

Using advanced CAD technology, professionals can carefully construct a three-dimensional digital model of CH based on the information obtained from big data analysis. This model not only accurately reproduces the appearance of CH, such as every brick and stone of the building and every texture of the sculpture, but also restores its visual effects such as colour, light and shadow through high-precision rendering technology, making the digitally reproduced CH lifelike, as if it had come through time and space and presented to the audience. As shown in Figure 5, this digital model is not only a visually shocking experience but also an important innovation in CH protection and inheritance.

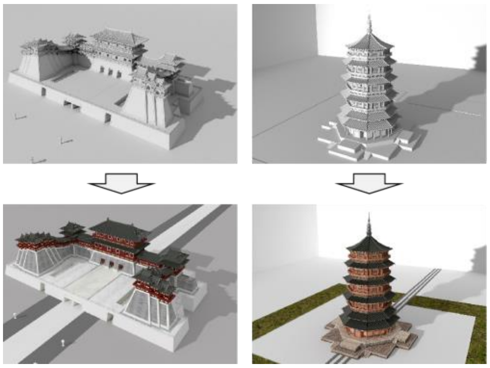

Figure 5: Digital reproduction of CH.

The model is not only used for exhibition but also can be used as the basis for subsequent protection, restoration and planning. In the protection work, the model can help experts make an accurate restoration plan, simulate the restoration process, and even predict the effect after restoration. In the planning work, the model can be used as the basis for designing new facilities or adjusting the existing layout to ensure the harmonious coexistence of new facilities and CH.

(4) Decision Support and Pre-alarm System: Combining the results of big data analysis and CAD model, an intelligent decision support system is developed. The system can integrate various information, such as the historical background, current situation, potential risks and protection costs of CH, and provide a comprehensive reference for decision-makers.

Decision support: using a multi-attribute decision-making method

$$D = \sum_{i=1}^{n} \omega_i \cdot a_i \tag{8}$$

D : decision score;

ω_i : the weight of the i attribute;

a_i : the score of the i attribute.

At the same time, an intelligent pre-alarm system based on big data should be built. The system can monitor the status of CH in real-time, find the abnormal situation in time through data analysis, and send out pre-alarm signals.

Pre-alarm system: using logistic regression to detect anomalies.

$$P\left(Y=1\middle|X\right) = \frac{1}{1+e^{-\left(\beta_0+\beta_1 X_1+\ldots+\beta_n X_n\right)}} \tag{9}$$

$P(Y=1|X)$: the probability of an event under a given feature X ;

$\beta_0,\beta_1,\ldots,\beta_n$: model parameters.

This helps the protection personnel to take timely measures to prevent the expansion and deterioration of potential risks, thus ensuring the safety and integrity of CH.

(5) Virtual exhibition and interactive experience: Using VR technology, combining CAD three-dimensional model and big data analysis results, creating an immersive virtual exhibition, enabling the public to experience the charm of CH personally, and enhancing public participation and social influence of CH.

4.2 Innovative Practice Cases

(1) Digital restoration

Combining the results of CAD three-dimensional modelling and big data analysis, CH can be digitally repaired accurately. Firstly, the three-dimensional model of CH is constructed by using CAD technology, and its current physical state and structural characteristics are recorded in detail. Then, through big data analysis, the disease type, distribution and severity of CH were identified. On this basis, using the modelling and editing functions of CAD, the diseased area is virtually repaired, different repair schemes are simulated, and their effects are evaluated (Figure 6).

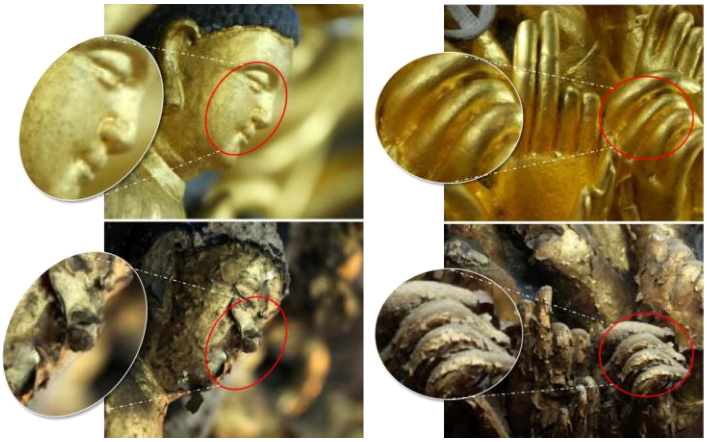

Figure 6: Effect of repair scheme.

Finally, according to the assessment results, the optimal repair scheme can be selected for actual construction. This digital restoration method not only improves the accuracy and efficiency of restoration but also reduces the interference to the original appearance of CH. The restoration accuracy and efficiency of this method are shown in Figure 7.

Experimental data show that the accuracy of the digital restoration method reaches 98%. Such high-precision restoration ensures that the historical information and artistic value of CH are preserved to the greatest extent. In terms of efficiency, the digital restoration method also performed well.

(2) Virtual exhibition and interactive experience

Using VR technology and big data analysis, you can create an immersive virtual exhibition and provide the public with a new way of CH experience. Through CAD three-dimensional modeling, the virtual scene and exhibit model of CH is constructed. Then, combined with the results of big data analysis, the interactive content and navigation route are designed so that the public can freely explore the historical, cultural, and artistic value of CH in the virtual environment. The virtual scene and exhibit model are shown in Figure 8.

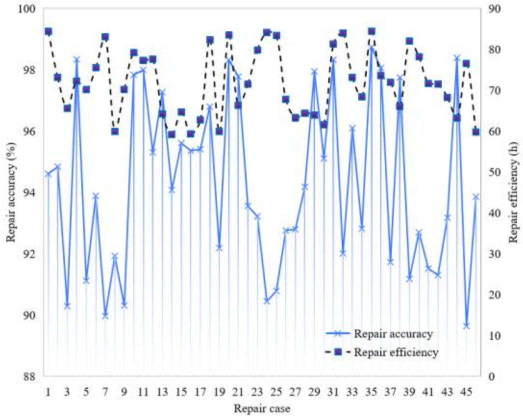

Figure 7: Repair accuracy and efficiency.

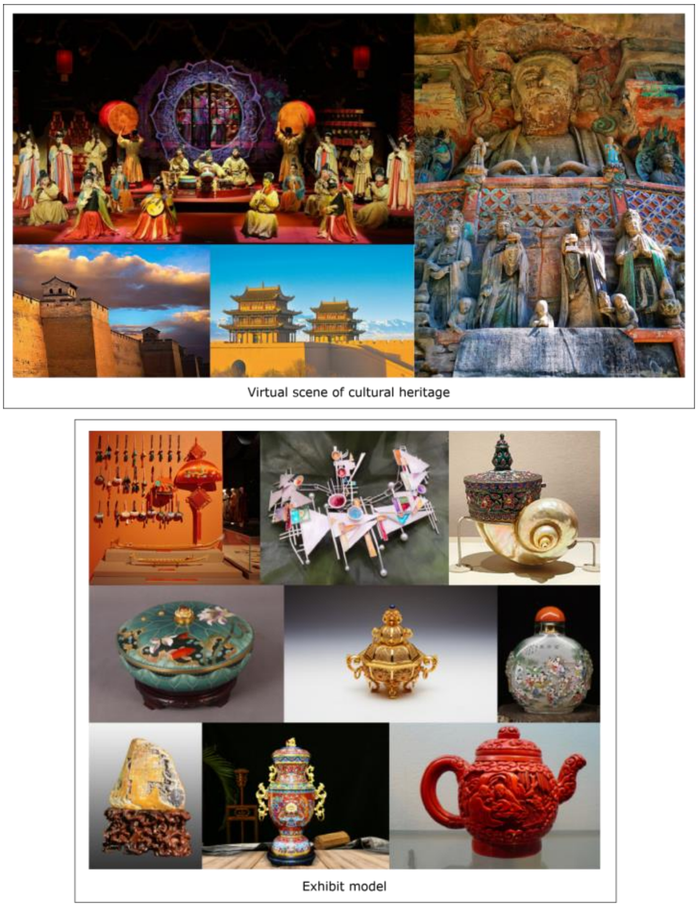

Figure 8: CH's virtual scene and exhibit model.

This kind of virtual exhibition not only breaks through the limitation of time and space but also enhances the public's sense of participation and experience, which helps to enhance CH's social awareness and influence.

(3) Intelligent pre-alarm system

Building an intelligent pre-alarm system based on big data can monitor the status of CH in real-time and prevent potential risks. The system collects the environmental parameters (such as temperature, humidity, vibration, etc.) and physical state data of CH in real-time through devices such as Internet of Things sensors. These data are transmitted to the big data platform for real-time processing and analysis. By setting a pre-alarm threshold and establishing a pre-alarm model, the system can find and warn potential risks and diseases in time, and provide timely decision support for protection personnel. The pre-alarm accuracy and false alarm rate are shown in Figure 9:

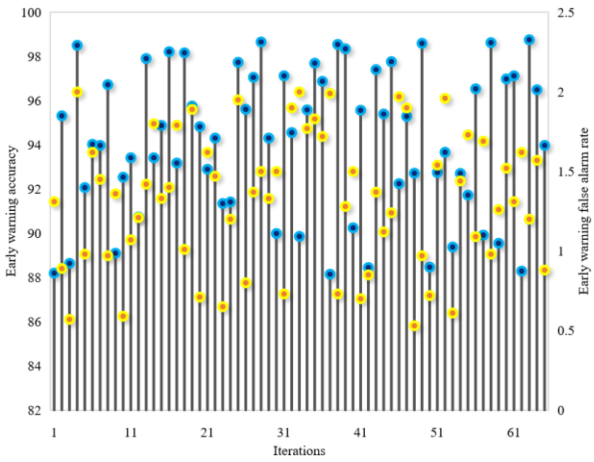

Figure 9: Pre-alarm accuracy and false alarm rate.

Experimental data show that the accuracy of the pre-alarm system is as high as 95%. This high accuracy ensures that the protection personnel can quickly respond to real threats and take effective measures. At the same time, the false alarm rate of the system is controlled at a very low level, which is 2%. The low false alarm rate reduces unnecessary intervention and waste of resources and also maintains the credibility of the pre-alarm system.

5 CONCLUSIONS

In this study, the innovative practice of integration of CAD and big data in CH protection and inheritance is deeply discussed, and the framework of integration technology is put forward; innovative practice cases such as digital restoration, virtual exhibition and interactive experience, and intelligent pre-alarm system are analyzed. At the same time, it also points out the current technical challenges and puts forward corresponding countermeasures. Research indicates that CAD and big data integration offer novel approaches for safeguarding and perpetuating CH, enhancing protection efficiency, fostering public engagement, and promoting sustainable CH development.

Future research avenues include: (1) Advancing technology integration and innovation, encompassing the development of efficient algorithms, refining 3D modelling, and enhancing data analysis accuracy and real-time capabilities. (2) Fostering interdisciplinary collaboration, merging insights from history, art, computer science, and other fields to deepen CH protection and inheritance research. (3) Assessing the societal implications of technology application, evaluating its impact on CH protection, cultural continuity, and socio-economic development to inform policy decisions scientifically.

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