International Journal for Housing Science and Its Applications
Publish August 10, 2025. Volume 46, Issue 4 Pages 3908-3918

https://doi.org/10.70517/ijhsa464511a

A Study on the Innovative Practices and Value of Digital Curation in Enhancing the Preservation of Cultural Heritage in Housing

Chenbo Dai[1] and Mingjin Wang[2,*]
[1] Department of Art, Sahmyook University, 01795, South Korea
[2] College of Art and Design, Yellow River Conservancy Technical Institute, Kaifeng, Henan, 475000, China
Corresponding authors: (e-mail: 2023931210@yrcti.edu.cn).

Abstract Through the intersection of digital technology and culture, it provides more diversified support for the diversified display, expression and experience of housing cultural heritage, thus generating a more multi-level and expressive interactive experience. In this study, a digital twin architectural model of housing cultural heritage is established based on point cloud modeling and finite element modeling, and combined with the field survey data of housing cultural heritage. Subsequently, the digital curation of housing cultural heritage is realized with the architectural modeling technology and virtual interaction technology. The digital model of housing cultural heritage constructed by the method proposed in this paper has a high degree of similarity with the housing building entity, and the average offset distance of the basic unit points is only 0.034 meters. The results of the case study show that the housing cultural heritage has been effectively protected after the implementation of digital curation, and the mean scores of the assessment of environmental, historical, scientific, and cultural values are between 8.25 and 8.99, which indicates that digital curation plays an important value in the innovative protection of housing cultural heritage. The significance of the research in this paper is that it accumulates original information for the digital preservation of housing cultural heritage and provides theoretical basis and technical support for more digital innovative preservation of housing cultural heritage.

Index Terms digital twin model, point cloud modeling, digital curation, architectural model, housing cultural heritage

I. Introduction

Architectural cultural heritage is the crystallization of human wisdom, which not only embodies the value of history, culture and art, but also provides valuable reference and inspiration for the development of architectural engineering technology. However, due to the passage of time and the aging of its own material and other factors, the protection of architectural cultural heritage has become very urgent [1]-[4]. With the development of science and technology, digital technology is gradually emerging in the field of architectural culture preservation and utilization. Digital protection and utilization of architectural cultural heritage is not only conducive to the protection of cultural heritage, but also can better promote and inherit architectural culture [5]-[8].

The traditional way of protecting architectural cultural heritage mainly relies on physical means, such as using reinforcement, repair, restoration and reconstruction to protect the integrity and irreplaceability of cultural heritage. However, there are many problems in this way, such as greater technical difficulty, higher cost, and difficulty in completely guaranteeing the original appearance of cultural heritage [9]-[12]. And digital technology plays an important role in the protection and inheritance of architectural cultural heritage. Its application mainly includes three stages: digital acquisition stage, digital protection processing stage and digital display dissemination stage [13], [14]. Through the application of digital technology, we can better protect ancient buildings, restore damaged buildings, record and inherit architectural details and decorations, as well as promote the inheritance and development of ancient architectural culture. In the era of digitization, we have the responsibility and obligation to protect and pass on the ancient architectural cultural heritage by using advanced technology, so that these valuable cultural treasures can be passed on forever [15]-[18].

Literature [19] aims to develop a DPUKV approach to preserve and utilize architectural heritage. A qualitative and longitudinal approach was used to construct a technical framework to realize digital resources for architectural heritage. The method was also validated using Chinese architectural heritage as a case study. The results show that the method is not only beneficial to the preservation of architectural heritage, but also applicable to other types of cultural heritage. Literature [20] discusses the relationship between disasters, digitization and architectural heritage conservation. By analyzing the potential of digital technology in architectural heritage preservation, it

emphasizes that digital twin and deep learning are the current hotspots of digital preservation research. It also summarized the technologies involved in architectural heritage preservation and proposed research directions such as accurate multi-hazard prediction and intelligent monitoring of human-computer interaction. Literature [21] emphasizes the requirements of the times for the protection of architectural cultural heritage and shows the important role played by information digitization technology in this protection. It also describes in detail the protection of digitization technology for the architectural cultural heritage of “Wutai Mountain Longquan Temple stone tablet”. Literature [22] adopts a scientific and standardized classification method to integrate architectural heritage into multi-level and multi-dimensional information in order to realize the protection of architectural heritage. By analyzing the BIM technology, constructing a “family” library, and taking a historical building site as a research object, the effectiveness of this method is verified, and it is capable of restoring and protecting architectural heritage. Literature [23] presents an overview of the digital twin concept in areas such as architecture and explores its application in the context of preserving architectural heritage, especially masonry. A prototype of the digital twin paradigm for preserving the structural integrity of heritage buildings is proposed. Literature [24] uses CiteSpace software to visualize and compare the keywords of related literature, and discusses the research directions and hotspots, the current status of research and limitations, and introduces the application and development of high-tech means in the field of architectural heritage conservation.

Literature [25] mentions the application of 3D laser scanning technology in architectural heritage preservation and proposes an effective architectural heritage information model that connects the architectural heritage to the BIM “family”. Based on the relationship between the two, a parameter-induced graphical drive is realized. Literature [26] examined the application value of VR technology in ancient architecture conservation. The architectural heritage information model was constructed by collecting data and drawing plane graphics to realize the integration of comprehensive information of historical buildings. And VR technology was utilized to demonstrate the effect of digital display and preservation, providing new ideas and methods for architectural heritage protection. Literature [27] explores the use of technology in the preservation of architectural heritage and interior spaces. Not only does it emphasize the importance and social value of digital preservation, but also points out its ability to form measures that shape cultural heritage. Literature [28] used blockchain DAO technology to study the digital storage, display and dissemination of Ribbon Mansion, indicating the problems of digital regeneration of cultural heritage. And the digital heritage preservation of historical sites in the virtual world was elaborated through questionnaires, combined with influence relations and sample cluster analysis methods. Literature [29] outlines the application of AI in the preservation of architectural cultural heritage, and introduces the concept of “developmental responses” for a better understanding of the preservation and utilization of AI in architectural cultural heritage. Literature [30] discusses the coupling relationship between architectural heritage conservation and tourism development by utilizing the concept of architectural heritage conservation and tourism development with coupling theory. The results of classification of architectural heritage and quantitative indicators were realized through cluster analysis method. The results show that the method is able to classify architectural heritage and quantify its factors.

In this paper, digital twin modeling technology and virtual interaction technology are combined to propose a digital curatorial path for the innovative protection of housing cultural heritage, which effectively improves the protection effect of housing cultural heritage. After collecting relevant architectural data of the housing cultural heritage, the geometric digital model of the housing cultural heritage is constructed by combining the point cloud modeling method and the building information modeling method. The physical characteristics and constraints are introduced into the geometric digital model, and the physical model of the housing cultural heritage is constructed based on the finite element modeling technique. Then the behavioral model and rule model of the housing cultural heritage are designed according to the time scale and historical data to realize the digital architectural model of the housing cultural heritage. Afterwards, we design the realization path of digital curation of housing cultural heritage by combining the virtual interaction technology supported by Leap Motion dynamic capture. This study first verifies the reliability of the digital modeling technology of housing cultural heritage, and then explores the protection effect of housing cultural heritage after the implementation of the designed digital curation path of housing cultural heritage through the empirical case study, in order to analyze the promotion role and practical value of digital curation in the protection of housing cultural heritage.

II. Method

II. A. Digital modeling of housing cultural heritage

II. A. 1) Digital twin modeling framework design

The digital twin model of housing cultural heritage is a large-scale data-driven model aimed at integrating the multi-physical, multi-scale and multi-probabilistic simulation process of the whole life cycle of housing cultural heritage, and comprehensively capturing the data information of housing cultural heritage through multi-level real-time/quasi-

real-time situational awareness and hyper-real-time virtual extrapolation. Based on the above concept, for the needs of digital curation of housing cultural heritage, this study combines the existing digital twin model to give the framework of housing cultural heritage digital twin model [31], which is visualized in the following expression:

$$M_{HBDT} = \{HBPE, HBDT, HBDD, HBSs, HBCN\} \tag{1}$$

where M_{HBDT} represents the housing cultural heritage digital twin model, $HBPE$ represents the housing cultural heritage physical entity, $HBDT$ represents the housing cultural heritage digital twin, $HBDD$ represents the housing cultural heritage twin data, $HBSs$ represents the housing cultural heritage intelligent monitoring and diagnostic service, and $HBCN$ represents the connectivity relationship between different dimensions. The organizational structure of the housing cultural heritage digital twin digital model is shown in Figure 1. $HBPE$ represents the objectively existing housing cultural heritage as well as the deployed sensors with significant hierarchy and interdependence. From the perspective of structural framework analysis, it is divided into unit-level PEs (columns, beams, squares, etc.), system-level PEs (foundation, upper load-bearing structure, enclosure system, etc.), and complex system-level PEs (housing cultural heritage ontology) to facilitate systematic analysis and efficient management. $HBDT$ specifically refers to the real mirror model of physical entities created through digitalization, which accurately portrays the physical entities of housing cultural heritage in “multi-dimensional, multi-perspective, multi-breadth, and multi-granularity”, and is responsible for obtaining and feeding back the data information of physical entities of housing cultural heritage. $HBDD$ mainly consists of housing cultural heritage physical entities, digital twins, services and other data is the housing cultural heritage digital twin ant motion and core. Through the construction of high-dimensional multi-dimensional heterogeneous static and dynamic databases, the housing cultural heritage twin data will provide holographic data of housing cultural heritage, eliminate information silos, satisfy the consistency and synchronization needs of the information space and the physical space, and provide data support for the digital twin of housing cultural heritage by constantly renewing and expanding the data on the basis of integration. $HBSs$ By integrating and encapsulating various types of data, algorithms, and results required in the operation of the digital twin model framework for housing cultural heritage in a service-oriented manner, we can provide users with a self-viewing and interchangeable experience. $HBCN$ is used to enable the flow of information between the housing cultural heritage digital twin model frameworks. The connection synchronizes the two interactions of the main triangular parts of the framework (physical entities of housing cultural heritage, digital twins of housing cultural heritage, and intelligent monitoring and diagnostic services) and all maintain a high degree of consistency at the data level with the intermediate part (housing cultural heritage twin data), which allows the intermediate part to drive the entire framework operation.

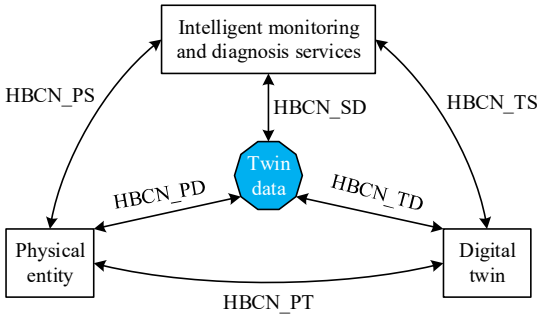

Figure 1: Digital twin model framework

II. A. 2) Methodology for digital modeling of housing cultural heritage

To ensure that the digital twin of housing cultural heritage is highly consistent with its physical entity in the real world, the construction of the digital twin of housing cultural heritage requires fusion modeling in the virtual environment from four key dimensions: geometric, physical, behavioral, and rules, which are visualized in the following expression:

$$HBDT = \{M_G, M_P, M_B, M_R\} \tag{2}$$

(1) Geometric model

Geometric model (M_G) is the digital reflection of the physical entity of housing cultural heritage, directly describes the geometric parameters of columns, beams, square and other components, accurately characterizes the internal

and external complex structure of housing cultural heritage, and is the first step in the modeling of housing cultural heritage digital twin. Usually, point cloud modeling or building information modeling methods can be used to complete the construction of the geometric model. Point cloud modeling is a geometric modeling technique that uses laser scanning and other measurements to collect dense point cloud data [32] to characterize the target surface, which can capture the complex details of the object, but its data volume is huge and requires high performance computing resources. Building information modeling [33] is a geometric modeling technique that integrates static structural modeling and object-oriented modeling to create 3D models that contain both geometric appearance and non-graphical features, which can encompass all the information of the object, but the degree of standardization varies, and there is a problem of compatibility between different platforms. Therefore, this study adopts a hybrid modeling method of point cloud and building information, integrating standard parametric model and irregular triangular mesh model, to restore the geometric appearance and non-graphical information of physical entities under the premise of maintaining the consistency of the data, which provides the basis for the subsequent model analysis and interactive operation.

(2) Physical model

Physical model (M_P) is based on the geometric model, by adding physical characteristics, constraints and other information to simulate the dynamic response of housing and cultural heritage in the natural environment or man-made forces. Usually, finite element modeling technology can be used to make mathematical approximations from macro and micro scales to construct a model reflecting the physical phenomena of housing and cultural heritage, and then use tools such as ABAQUS and ANSYS to carry out dynamic multi-scale simulation and analysis. Combined with real-time data streaming for continuous training and optimization of the model, a high-level mapping of the physical entities of the housing cultural heritage is achieved, providing an offline physical field model library for the housing cultural heritage digital twin.

(3) Behavioral model

Behavioral model (M_B) mainly describes the real-time behaviors of physical entities of housing and cultural heritage under the coupling of external environment and internal causes in different time and space scales. The construction of behavioral model is a systematic process, which firstly needs to clarify the purpose and application scenarios of the model construction, collect relevant data to provide necessary inputs for the model, select appropriate modeling methods after bribery, construct the behavioral model and carry out validation and calibration, and finally, carry out continuous updating and optimization based on new data.

(4) Rule Model

The rule model (M_R) describes the rules extracted from the historical data of housing cultural heritage, including data association, generalization of tacit knowledge, and design specifications for wooden structures. The construction of the rule model can rely on the summarization of existing experience, or it can be used to continuously mine updated rules in an automated way with the help of advanced data analytics technologies, such as machine learning and data mining.

II. B.Digital curatorial design for housing cultural heritage

II. B. 1) Digital interaction technologies

In the digital curation of housing cultural heritage designed in this paper, based on the use of Touch Designer software, real-time image acquisition and gesture recognition are carried out using Leap Motion motion capture [34], and representative gestures are extracted by analyzing the characteristic points, so as to enable the viewers to directly interact with the housing cultural heritage. This somatosensory interaction technology not only breaks the boundaries of space and roles, but also enables the viewers to deeply experience the unique charm and deep emotions of housing cultural heritage in the interaction. In addition, the work also adds a well-designed background music and visual performance, the perfect combination of music and images, so that the audience can enjoy the work at the same time, but also feel a kind of spiritual shock and emotional resonance.Leap Motion somatosensory interactors use optical tracking technology, the device has two high-resolution cameras, three sets of infrared LED indicators and optical sensors. The two cameras capture the user's gestures from multiple angles, enabling precise tracking of the target object to produce a three-dimensional infrared image.The Leap Motion device is controlled using a right-handed coordinate system, constructing a right-angled coordinate frame with the center of the sensor as the starting point. The frame consists of three axes, with the X-axis extending to the right along the long side of the device, the Z-axis pointing forward along the short side of the device, and the Y-axis pointing perpendicular to the surface of the device, above the sensor. This design allows Leap Motion to recognize a user's hand movements with high accuracy, providing a richer and more intuitive way of human-computer interaction.

Digital curation of housing cultural heritage builds virtual environments based on gesture interaction through Leap Motion devices. Leap Motion's gesture interaction mechanism begins with the capture of gestures, the built-in camera captures the user's hand movements, the system performs preliminary processing of these movements,

identifies a specific gesture, and performs an in-depth analysis of these movements using gesture modeling technology. After the analysis is complete, the system generates the corresponding gesture descriptions based on the results of the analysis and performs the application feedback that corresponds to the user's gestures. This series of steps not only demonstrates Leap Motion's efficiency and precision in gesture recognition and interaction, but also reveals its potential for a wide range of applications in the field of human-computer interaction technology.

II. B. 2) Digital Curation Realization Paths

Digital curation refers to the process of transforming elements such as the main body of housing architectural cultural heritage, regional characteristics or history and culture into visual elements suitable for modern media through digital technology. Through digital curation not only can timely protect and repair problems in housing cultural heritage, but also through virtual interaction can enhance the audience's deep understanding of the value of housing cultural heritage and realize the protection of housing cultural heritage. Visual translation [35] is the core means of information storage, reconstruction and dissemination in cultural heritage protection. The study of digital visual translation of housing cultural heritage can provide practical case references for the construction of relevant digital curatorial platforms. In this paper, based on the digital modeling method of housing cultural heritage, the specific path of digital curatorial realization of housing cultural heritage is designed as shown in Figure 2. The combination of housing cultural heritage and digital devices can realize the visual presentation of housing cultural heritage from figurative to abstract. Figurative visualization refers to the reproduction of the external form, building materials, building components and roof shape of the housing cultural heritage, so as to realistically restore the historical scene and appearance of the housing cultural heritage. Abstraction refers to showing the inner spiritual qualities of housing cultural heritage, such as ideological characteristics and cultural meaning, and refining, deforming or reorganizing them through digital technology and multimedia means, so as to make the audience feel the inner spirit and aesthetic value of housing cultural heritage. In the digital curatorial del visual translation design, science and technology should be skillfully integrated with aesthetic art, with the help of digital technology innovation, making the digital visual translation design results fascinating and artistic charm. The visual translation of housing cultural heritage firstly utilizes digital technology to generate variable graphics and animations. These visual elements not only enrich the design language, but also enhance the expressive power of the work. Secondly, the light and color are controlled through digital technology to produce visual effects that harmonize with the space. It gives the works deeper emotional expression and visual impact. Digital technology can realize the innovative construction of space and form, creating abstract dynamic effects coordinated with movement and power these dynamic effects not only enhance the vitality of the work, but also allow users to feel a dynamic rhythm and vitality in the viewing process.

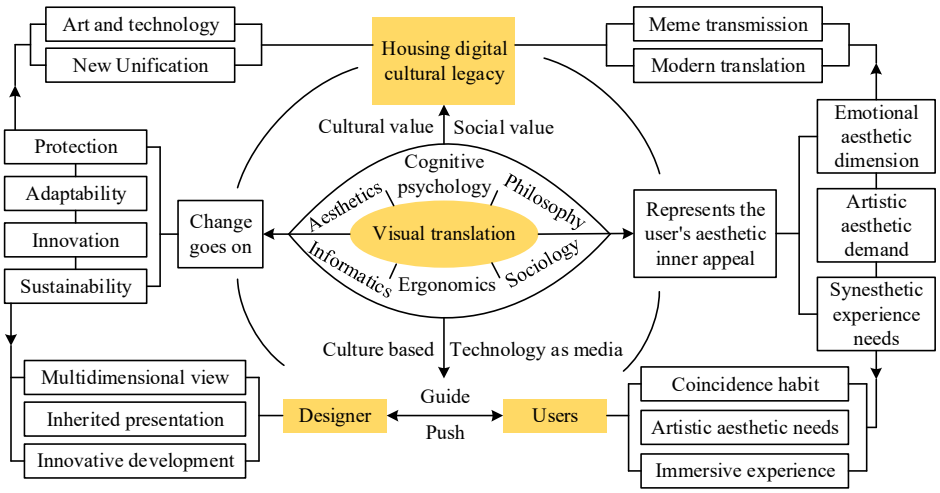

Figure 2: The digital visual translation path of the housing cultural heritage

III. Results and discussion

III. A. Quality assessment of digital modeling of housing cultural heritage

III. A. 1) Subject of the study

Located in Pingyao County, Jinzhong City, Shanxi Province, Pingyao Ancient City was built during the reign of King Xuan of the Western Zhou Dynasty, and is one of the best-preserved architectural cultural heritages in China today. The city consists of walls, stores, streets, temples, and houses, which together form a large housing and cultural

heritage complex. The streets and housing buildings in Pingyao Old Town, which reflect their original historical appearance, are known as living samples of China's architectural cultural heritage, and are rich in unique architectural, religious, commercial, folkloric, and folk art values. This paper takes the housing cultural heritage of the four main streets of Pingyao as the object of study, analyzes the main contents related to the street scale, commercial business and place activities of the four main streets of Pingyao through data collection, survey and statistics, and surveying, and constructs a three-dimensional digital model of the housing cultural heritage of the four main streets of Pingyao by using architectural three-dimensional modeling technology. The statistical results of the architectural distribution of the four main streets of Pingyao Ancient City are shown in Figure 3. Overall the South Street in Pingyao Old Town has a higher number of housing cultural heritage buildings (726), with accommodation as well as amenity buildings accounting for 31.51% and 26.88% respectively. On the other hand, the vitality of the East Main Street is the worst, in which the number of closed stores for rent is 40, accounting for 56.34% of the total number of closed stores for rent, resulting in few tourists on the East Main Street, which contrasts sharply with the scene of crowds of people and shoulder-to-shoulder traffic on the other three Main Streets at the same time.

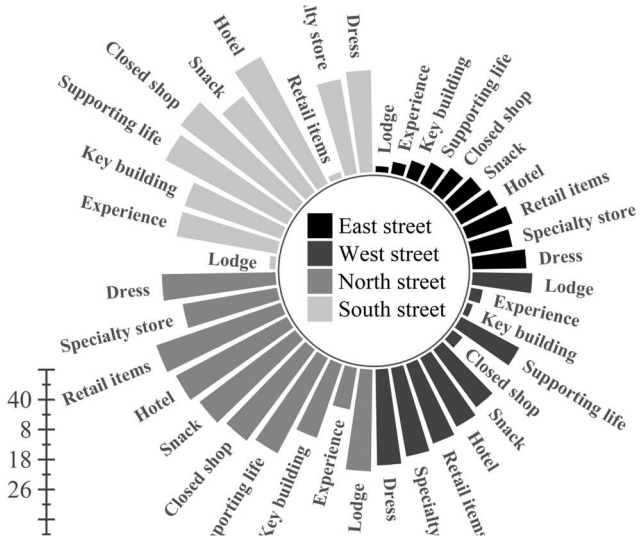

Figure 3: Statistical results of the construction distribution of Pingyao ancient city

III. A. 2) Evaluation indicators

This paper adopts the idea of applying the local to evaluate the whole, and uses the random sampling method to calculate the geometric accuracy of the digital model of housing cultural heritage. Since the basic unit point and basic unit line are the basic components of the 3D model, the characteristics of the basic unit point and basic unit line are analyzed, and the spatial geometric accuracy of the 3D model is evaluated from four aspects: the distance offset d of the basic unit point, the length difference l of the basic unit line, the distance offset d' and the angle offset α.

(1) Evaluation of basic unit points

Using coordinates to represent the position of points in space, let $P(x,y,z)$ be any point in the 3D model, called the basic unit point. Randomly select n corner points in the constructed model, which are labeled as $M_i(x_i,y_i,z_i)$ and $i\in[1,n]$, and then correspondingly select the real points $N_j(x_j,y_j,z_j)$ and $j\in[1,n]$ of the building entity in the point cloud data, and calculate the distance difference between M_i and N_i according to the formula:

$$\left|M_iN_j\right|=\sqrt{\left(x_j-x_i\right)^2+\left(y_j-y_i\right)^2+\left(z_j-z_i\right)^2} \tag{3}$$

The mean value of n corner point distance difference is calculated as the basic unit point distance difference d as in equation (4):

$$d=\frac{1}{n}\sum_{i,j=1}^{n}\left|M_iN_j\right| \tag{4}$$

(2) Evaluation of basic unit line

The digital model of the building can be visualized through the basic unit line, and the positions of the line segments are determined by the endpoints $P_1(x_1,y_1,z_1)$ and $P_2(x_2,y_2,z_2)$ of the line segments, and the length difference 1, distance offset d' and angle offset α of the line segments are used for the evaluation of the basic unit line. The endpoints $M_1(x_1,y_1,z_1)$, $M_2(x_2,y_2,z_2)$ of the line segment L_M selected in the constructed architectural digital model and its corresponding endpoints $N_1(x_3,y_3,z_3)$, $N_2(x_4,y_4,z_4)$ of the line segment L_N in the point cloud data of the digital model of the cultural heritage of the ancient city of Pingyao, the length difference of L_M, L_N are calculated as in Equation (5):

$$\begin{aligned}\left|L_M\right|-\left|L_N\right| &= \sqrt{\left(x_2-x_1\right)^2+\left(y_2-y_1\right)^2+\left(z_2-z_1\right)^2} \\ &-\sqrt{\left(x_4-x_3\right)^2+\left(y_4-y_3\right)^2+\left(z_4-z_3\right)^2}\end{aligned} \tag{5}$$

Randomly select m basic unit line at the edge of the model and calculate the average of their length differences, Eq:

$$a=\frac{1}{m}\sum_{i=1}^{m}\left(\left|L_M\right|-\left|L_N\right|\right)_i \tag{6}$$

m basic unit lines are randomly selected and the distances between the endpoints and midpoints of the constructed digital model L_M to the endpoints and midpoints of the corresponding point cloud data L_N are calculated, denoted as $\left|M_1N_1\right|$, $\left|M_2N_2\right|$, and $\left|P_aP_b\right|$. The difference in the distances of these m lines is calculated and averaged, denoted as the distance offset value b, Eq:

$$b=\frac{1}{3m}\sum_{i=1}^{m}\left(\left|M_1N_1\right|+\left|M_2N_2\right|+\left|P_aP_b\right|\right) \tag{7}$$

The angle α between the basic unit line M_A of the build model and M_B of the point cloud data, as in Eq:

$$\alpha=\arccos\left(\frac{x_ax_b+y_ay_b+z_az_b}{\sqrt{x_a^2+y_a^2+z_a^2}\cdot\sqrt{x_b^2+y_b^2+z_b^2}}\right),\theta\in\left(0,\frac{\pi}{2}\right] \tag{8}$$

where, $x_a=x_2-x_1$, $y_a=y_2-y_1$, $z_a=z_2-z_1$, $x_b=x_4-x_3$, $y_b=y_4-y_3$, $z_b=z_4-z_3$. Similarly, m basic unit lines are randomly selected for averaging as the angular offset values of the basic unit lines of the Anhua County Literature Temple.

Randomly selected n basic unit lines are averaged as the angular offset of the basic unit line of this 3D model c, calculated by the formula:

$$c=\frac{1}{m}\sum_{i=1}^{m}\alpha_i \tag{9}$$

III. A. 3) Results of digital model quality analysis

The digital model of housing cultural heritage is decomposed into basic unit points and basic unit lines, and the points and lines with obvious distribution characteristics and representativeness are selected. 10 basic unit points and 6 basic unit lines are selected through random sampling. Taking the data measured by the 3D laser scanner as the actual value, obtain the control point coordinates of the corresponding basic unit points and lines respectively. The distance offset d of the basic unit points, the length difference l of the basic unit lines, the distance offset d' and the angle offset α of the housing cultural heritage are calculated, and the quality analysis results of the housing cultural heritage digital model are shown in Table 1. The average offset distance of the basic unit points of the digital model of housing cultural heritage constructed using the method proposed in this paper is 0.034 meters. A basic unit point is determined by at least two intersecting lines, the more intersecting lines the more information the point contains, the higher the precision, the basic unit point determined by only two intersecting lines contains the least information, and the precision of the unit point is low. The average line distance bias and line angle bias of the basic unit lines of the digital model of housing cultural heritage were 0.021 m and 1.950°, respectively. There are two main types of line locations in the digital model, one is the line segments at the edges that constitute the model, and the other is the line segments intersected by two planes, and the line segments intersected by two

planes contain more information and have higher geometric accuracy. In the model construction, the basic unit lines used are mostly straight lines, so the angular offset is small, and the angular offset will be larger for the components with curvature such as roofs and tiles. From the analysis of data indicators, it can be concluded that the 3D architectural model of housing cultural heritage constructed by the method proposed in this paper has a high degree of similarity with the housing building entity, which lays a technical foundation for the realization of digital curation of housing cultural heritage.

Table 1: Evaluation of geometric accuracy of housing cultural heritage model

Categories	Sample point	Evaluation index	
		d (m)	l (m)
Basic unit point	1	0.008	0.020
	2	0.041	0.020
	3	0.036	0.049
	4	0.043	0.044
	5	0.019	0.017
	6	0.034	0.002
	7	0.060	0.012
	8	0.051	0.047
	9	0.024	0.009
	10	0.023	0.028
	Average	0.034	0.025
Categories	Sample point	Evaluation index	
		d' (m)	α (°)
Basic line	1	0.030	1.438
	2	0.009	2.362
	3	0.030	2.391
	4	0.025	1.521
	5	0.017	2.220
	6	0.017	1.770
	Average	0.021	1.950

III. B. Analysis of the effectiveness of the protection of the cultural heritage of housing

III. B. 1) User interaction experience analysis

In order to investigate the deficiencies in the designed Pingyao Ancient City housing cultural heritage digital curation technology, this paper analyzes a number of major problems in digital curation through surveys and analyses, such as confusing system operation, fuzzy navigation, and a single way of displaying, etc. The results of the survey and analysis of the user's interactive experience in digital curation are shown in Figure 4. A-F in the figure represent the operation guide, beautiful interface, navigation guide, introduction of housing and cultural heritage, background music and interesting interaction in digital curation respectively. Among them, 72.70% of the users thought that the navigation in the digital curation of the housing and cultural heritage of Pingyao Old Town was clear and that it was not easy to lose the sense of direction in the virtual environment, and 81.30% of the users thought that the digital curation was highly interesting. The proportion of users with survey scores of 4 and 5 in the remaining indicators was higher than 70%, indicating that the restoration of virtual scenes and digital interaction in the digital curation of housing cultural heritage achieved good results. In addition, it was found that the introductory information of housing cultural heritage in digital curation is an indispensable element, which is a direct way to disseminate and protect housing cultural heritage. Therefore, the presentation information of housing cultural heritage from the user's perspective is necessary. Appearance is the most important information that users want to view, followed by the historical background behind the housing cultural heritage.

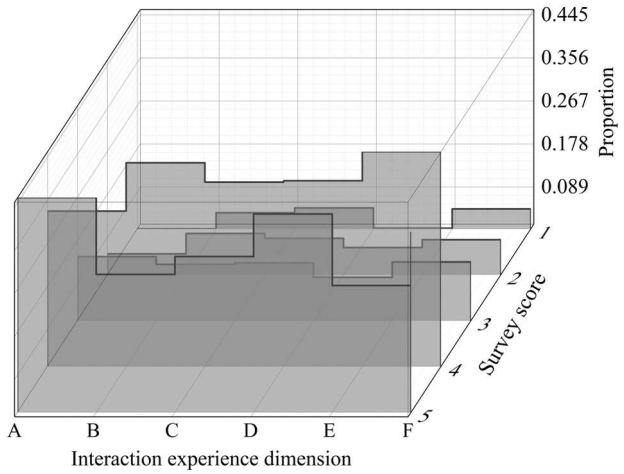

Figure 4: User interaction experience analysis results

III. B. 2) Analysis of the effectiveness of the protection of cultural heritage in housing

The realization of the digital curation of the housing cultural heritage of the ancient city of Pingyao not only achieves architectural conservation and coordinated planning, but also promotes the dissemination of housing cultural heritage. It enables the public to gain a deeper understanding of the historical and cultural values of the housing cultural heritage of the ancient city of Pingyao, and stimulates a positive attitude towards the protection of the housing cultural heritage of the ancient city of Pingyao during field visits, thus realizing the protection of the housing cultural heritage. Therefore, this paper analyzes four aspects, namely, environmental value, historical value, scientific value and cultural value, which were evaluated and analyzed by 10 experts in the field of housing cultural heritage. The results of the analysis of the effect of the protection of housing cultural heritage in Pingyao Old Town are shown in Table 2. On the whole, the assessment grades of the housing cultural heritage of Pingyao Old Town in terms of environmental value, historical value, scientific value and cultural value after the realization of digital curation are excellent (8.99 points), good (8.45 points), good (8.25 points) and excellent (8.70 points), respectively. The construction control zone is the main component of the scientific value of the housing cultural heritage, and the protection of the construction control zone can ensure the integrity of the spatial pattern of the housing cultural heritage, and at the same time play the role of buffer and scenery for the core protection zone. The Environment Coordination Zone, based on the natural landscape environment, can have a certain impact on the traditional landscape of housing cultural heritage, and is an important indicator for judging whether the housing cultural heritage has been effectively protected at the overall level. From the results, the average scores of the expert assessment of the two indicators are 7.37 and 7.65 respectively, which are at a high level. In addition, housing cultural heritage is an important value carrier of historical information, but information is easily lost due to modernization. Strengthening the mapping and registration of housing cultural heritage and figuring out the basic data are conducive to enhancing the research and protection of housing cultural heritage. With the realization of digital curation, the assessment score of the mapping and registration of the housing cultural heritage of the Ancient City of Pingyao was 8.01, which indicates that digital curation plays an important value in the innovative protection of housing cultural heritage.

Table 2: Analysis of the protection effect of housing cultural heritage

Dimension		Assessment score		Protective effect
Environmental value	Surrounding mountain protection	9.09	8.99	Excellence
	Surrounding water protection	8.16		
	Surrounding vegetation protection	9.73		
Historical value	Historical events	8.98	8.45	Good
	Historical event publicity	8.23		
	Historical celebrity influence	7.00		
	Historical celebrity publicity	9.57		
Scientific value	Core reserve	7.95	8.25	Good
	Construction control area	7.37		
	Environmental coordination area	7.65		

	The integrity of street	7.43		
	The number of historic streets	8.54		
	The scale of historic street	8.46		
	The historic street floor is paved	9.21		
	Historical street facade landscape	9.38		
Cultural value	Mapping and registration of cultural heritage	8.01	8.70	Excellence
	Record and storage of cultural heritage	8.67		
	Folk culture influence	8.62		
	Cultural heritage of folk customs	9.19		
	Cultural show space scale	8.99		

IV. Conclusion

This paper combines digital twin modeling technology and virtual interaction technology to propose a specific realization path for digital curation of housing cultural heritage, examines the effectiveness of digital twin modeling technology, and explores the enhancement effect and practical value of digital curation on housing cultural heritage protection through empirical analysis. The results show that:

(1) The average offset distance of the basic unit point of the housing cultural heritage digital model constructed by the method proposed in this paper is 0.034 meters, and the average line distance offset and line angle bias of the basic unit line are 0.021 meters and 1.950° respectively, which proves that the architectural model of housing cultural heritage has a high degree of similarity to the housing architectural entity, and lays down a technical foundation for the realization of the digital curation of housing cultural heritage. This proves that the architectural model of housing cultural heritage has high similarity with the housing building entity, and lays a technical foundation for the realization of digital curation of housing cultural heritage.

(2) The evaluation grades of the housing cultural heritage in the environmental, historical, scientific and cultural values of the housing cultural heritage of Pingyao Ancient City were excellent (8.99 points), good (8.45 points), good (8.25 points) and excellent (8.70 points) respectively after the implementation of digital curation, indicating that digital curation has played an important role in the innovative protection of housing cultural heritage.

(3) The digital model of housing cultural heritage established on the basis of digital technology has enriched the resources of the digital model library, and provided accurate digital reference materials for information sharing, conservation and restoration, display and dissemination as well as conservation and development of housing cultural heritage, which has important practical value and influence on the conservation and development of housing cultural heritage.

References

[1] Moioli, R. (2015, December). Architectural Cultural Heritage and Sustainability: How Many Pillars. In Proceedings of the International Conference on Sustainability in Architectural Cultural Heritage, Limassol, Cyprus (pp. 11-12).
[2] Zhao, Y. (2022). Digital protection of cultural heritage based on web technology. Mathematical Problems in Engineering, 2022(1), 3196063.
[3] Portalés, C., Rodrigues, J. M., Rodrigues Gonçalves, A., Alba, E., & Sebastián, J. (2018). Digital cultural heritage. Multimodal Technologies and Interaction, 2(3), 58.
[4] Liang, W., Ahmad, Y., & Mohidin, H. H. B. (2023). The development of the concept of architectural heritage conservation and its inspiration. Built Heritage, 7(1), 21.
[5] Sedek, M. S., Touahmia, M., Albaqawy, G. A., Latifee, E., Mahioub, T., & Sallam, A. (2024). Four-Dimensional Digital Monitoring and Registering of Historical Architecture for the Preservation of Cultural Heritage. Buildings, 14(7), 2101.
[6] Marra, A., Trizio, I., & Fabbrocino, G. (2021, March). Digital Tools for the knowledge and safeguard of historical heritage. In International Workshop on Civil Structural Health Monitoring (pp. 645-662). Cham: Springer International Publishing.
[7] Zhong, H., Wang, L., & Zhang, H. (2021). The application of virtual reality technology in the digital preservation of cultural heritage. Computer Science and Information Systems, 18(2), 535-551.
[8] Khalid, A. (2021). Conservation challenges and emerging trends of digital preservation for UNESCO architectural heritage, Pakistan. Conservation, 2(1), 26-37.
[9] Borri, A., & Corradi, M. (2019). Architectural heritage: A discussion on conservation and safety. Heritage, 2(1), 631-647
[10] Quintana, D. C., Díaz-Puente, J. M., & Gallego-Moreno, F. (2022). Architectural and cultural heritage as a driver of social change in rural areas: 10 years (2009–2019) of management and recovery in Huete, a town of Cuenca, Spain. Land use policy, 115, 106017.
[11] Doğan, H. A. (2020). Perception of the modern movement in architecture as cultural heritage. Art History & Criticism, 16(1), 65-78.
[12] Abed, F. M., Mohammed, M. U., & Kadhim, S. J. (2017). Architectural and Cultural Heritage conservation using low-cost cameras. Applied Research Journal, 3, 376-384.
[13] Hua, G., & Jianfeng, H. (2020, July). Research on integration of digital protection of “Cultural Relics” architecture and virtual reality technology. In IOP Conference Series: Earth and Environmental Science (Vol. 546, No. 5, p. 052026). IOP Publishing.

[14] Lopes, R. O., Malik, O. A., Kumpoh, A. A. Z. A., Keasberry, C., Hong, O. W., Lee, S. C. W., & Liu, Y. (2019, September). Exploring digital architectural heritage in Brunei Darussalam: Towards heritage safeguarding, smart tourism, and interactive education. In 2019 IEEE Fifth International Conference on Multimedia Big Data (BigMM) (pp. 383-390). IEEE.
[15] Georgopoulos, A. (2018). Contemporary digital technologies at the service of cultural heritage. Heritage Preservation: A Computational Approach, 1-20.
[16] Ioannides, M., Fink, E., Brumana, R., Patias, P., Doulamis, A., Martins, J., & Wallace, M. (Eds.). (2018). Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection: 7th International Conference, EuroMed 2018, Nicosia, Cyprus, October 29–November 3, 2018, Proceedings, Part I (Vol. 11196). Springer.
[17] Trček, D. (2022). Cultural heritage preservation by using blockchain technologies. Heritage science, 10(1), 6.
[18] Masciotta, M. G., Morais, M. J., Ramos, L. F., Oliveira, D. V., Sanchez-Aparicio, L. J., & González-Aguilera, D. (2021). A digital-based integrated methodology for the preventive conservation of cultural heritage: the experience of HeritageCare project. International Journal of Architectural Heritage, 15(6), 844-863.
[19] Zhang, X., Zhi, Y., Xu, J., & Han, L. (2022). Digital protection and utilization of architectural heritage using knowledge visualization. Buildings, 12(10), 1604.
[20] Li, Y., Du, Y., Yang, M., Liang, J., Bai, H., Li, R., & Law, A. (2023). A review of the tools and techniques used in the digital preservation of architectural heritage within disaster cycles. Heritage Science, 11(1), 199.
[21] Wang, X., Wang, Y., Ma, L., Yuan, P., & Zhang, Y. (2020, October). Information processing technology in the digital protection of architectural cultural heritage. In 2020 International Conference on Culture-oriented Science & Technology (ICCST) (pp. 496-499). IEEE.
[22] Chen, Y., Wu, Y., Sun, X., Ali, N., & Zhou, Q. (2023). Digital documentation and conservation of architectural heritage information: An application in modern Chinese architecture. Sustainability, 15(9), 7276.
[23] Vuoto, A., Funari, M. F., & Lourenço, P. B. (2023). On the use of the digital twin concept for the structural integrity protection of architectural heritage. Infrastructures, 8(5), 86.
[24] Wang, J., & Lu, C. (2022, August). Research on the development and practice of digital technology in architectural heritage. In 2022 International Conference on Culture-Oriented Science and Technology (CoST) (pp. 146-150). IEEE.
[25] Hou, S. Q. (2016). A Design and Research on Protection of Architectural Heritage Based on Digital Technology. In MATEC Web of Conferences (Vol. 63, p. 02038). EDP Sciences.
[26] Zheng, H., Chen, L., Hu, H., Wang, Y., & Wei, Y. (2024). Research on the Digital Preservation of Architectural Heritage Based on Virtual Reality Technology. Buildings, 14(5), 1436.
[27] Mohammed Mahmoud Mohammed Ahmed, O. (2020). New approach for digital technologies application in heritage architecture conservation. International Journal of Artificial Intelligence and Emerging Technology, 3(2), 24-56.
[28] Hsiao, T. C., & Shen, S. (2023). A study of digital architectural heritage preservation based on blockchain technology. The Journal of Engineering, 2023(1), e12213.
[29] Shi, Y. (2023, January). Development Countermeasures of Artificial Intelligence in the Field of Architectural Cultural Heritage Protection and Utilization. In International Conference on Innovative Computing (pp. 164-169). Singapore: Springer Nature Singapore.
[30] Zhang, Y., He, L., & Tu, Z. (2022). The protection of architectural heritage in the process of urbanization under the internet environment. Mobile Information Systems, 2022(1), 7841789.
[31] Karim Kadry,Shreya Gupta,Farhad R Nezami & Elazer R Edelman. (2024). Probing the limits and capabilities of diffusion models for the anatomic editing of digital twins. NPJ digital medicine(1),354.
[32] Hang Nga Mai,Yong Gun Kim,Seok Hwan Cho,Tim Joda & Du Hyeong Lee. (2024). Enhancing dental education with a 3D point cloud comparison and augmented reality for auto-evaluation of fixed prosthodontic practice: An in vitro study. Journal of dentistry105493.
[33] Menna allah T. Mohamed,Naglaa A. Megahed,Merhan M. Shahda & Sara Eltarabily. (2024). Efficiency of utilizing building information modeling tools for examining smart materials behavior in a hot climate. Journal of Building Engineering108924-.
[34] Yu Tian,Yue Shi,Yuzhuo Wu,Wenhao He,Shuang Liu & Da Tao. (2024). Assessing mouse, trackball, touchscreen and leap motion in ship vibration conditions: A comparison of task performance, upper limb muscle activity and perceived fatigue and usability. International Journal of Industrial Ergonomics103585-.
[35] Pecot Fabien,Celhay Franck,Kacha Mathieu & Lombard Gautier. (2022). Expressions of the past: A practice-based approach of brand longevity visual translation in advertising. Journal of Business Research121-133.