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Research on the Digital Preservation of Architectural Heritage Based on Virtual Reality Technology

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Abstract: As a representative of the scientific and technological achievements of the new era, the overall development of virtual reality (VR) technology is becoming increasingly refined, which provides new development ideas and technical support in the field of ancient building restoration and architectural heritage preservation. In this context, digital conservation and the practice of architectural heritage have become important focuses of application in the industry. This paper starts from the core concept of VR technology, analyzes the value of the application of VR technology in the protection of ancient architecture, puts forward relevant suggestions and technical application methods, and takes Red Pagoda in Fuliang County as an example. In this sense, virtual reality technology is used to restore and protect the buildings, forming a digital heritage of ancient architecture. This study first utilizes a three-dimensional laser scanning instrument to collect point cloud data, and then the plane graph is drawn by measurement. Then, an Architectural Heritage Building Information Model is created, and comprehensive information on historical buildings is integrated. Finally, VR technology is used to show the effect of digital display and preservation. This study transforms architectural cultural heritage into a shareable and renewable digital form through restoration and reproduction, interpreting and utilizing it from a new perspective and providing new ideas and methods for architectural heritage conservation.

Keywords: virtual reality; architectural heritage conservation; 3D modeling; point cloud data processing

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1. Introduction

As a crucial component of cultural heritage, architectural heritage carries rich historical, cultural, and artistic connotations, making it an indispensable treasure of human civilization. The protection and inheritance of architectural heritage involves multiple subjects such as history, social economy, and urban planning and directly relates to the inheritance and prosperity of human cultural heritage. This work holds significant practical value and historical significance. It can help us to better protect and inherit the cultural heritage but also can bring development space for the cultural industry [1]. The conservation and inheritance of architectural heritage face a series of challenges. The rapid construction and renovation brought about by urbanization have led to many architectural heritage sites with historical value facing demolition or alteration, and how to effectively protect architectural heritage while meeting the demand for spatial renewal is a difficult problem that architects, urban planners, and cultural heritage protectors need to face. To effectively protect and inherit architectural heritage, digital conservation and display of architectural heritage through the use of scientific and technological means, such as digital conservation, virtual reality, multidimensional digital simulation, and other technologies, have become emerging cross-research fields of architectural science, computer science, and humanities at the same time [2].

VR is an innovation that synthesizes a wide range of technologies to produce a virtual three-dimensional spatial world using computer simulation to achieve a highly simulated experience [3]. Through virtual reality technology, we can obtain immersive sensory experiences such as visual, auditory, and tactile sensations, while the system is also capable of performing complex real-time calculations as the location changes; therefore, in terms of the presentation of architectural heritage, virtual reality technology is able to provide an all-encompassing display and experience. For the protection of architectural heritage, virtual reality technology is crucial. Models created by VR exhibit extremely high effectiveness: They can provide an immersive experience, allowing users to feel as if they are in a realistic virtual environment, which helps them to better understand and experience the features and applications of the model. Additionally, through VR, users can gain a more realistic sense of depth and scale, which is particularly important for models in design, architecture, or engineering fields. Users can receive real-time feedback, instantly see any changes to the model, and immediately assess the impact of these changes on the model [4]. It can create digital assets that preserve against irreversible damage caused by human factors or natural disasters and provide original references for the restoration of architectural heritage that has been exposed to long-term external conditions, such as weathering, fading, and fire. Moreover, in the process of communication, virtual reality technology can also reduce damage to ancient buildings, providing a clearer, more realistic, and more detailed representation of architectural heritage details. At the same time, digitizing and protecting architectural heritage can help extend its life span and value [5]. It is worthwhile to recognize that virtual reality technology also provides a more comprehensive and intuitive method for architectural display. Traditional architectural displays usually rely on static forms such as pictures, texts, or models to present the appearance and internal structure of a building, which makes it difficult for people to truly experience the atmosphere and details of the building [6]. Virtual reality technology can bring users into a virtual three-dimensional scene through virtual reality devices so that they can freely roam in all corners of the building and observe its details and appearance closely to understand the characteristics and charm of the building more deeply [7].

The case study analyzed in the present work is of Fuliang Red Pagoda in Jingdezhen, and by relying on digital technology modeling, the digital display process of the pagoda is realized, from which good interaction between the architectural heritage and the environment is achieved. Relying on VR technology, the audience can realize the reception and internalization of different levels of information from the digital architectural model of the pagoda in sensory organs such as hearing, vision, and touch. This study provides an effective technical reference for relevant staff in the field of architectural heritage protection and enriches the architectural heritage display of the Fuliang Red Pagoda by utilizing virtual reality technology [8]. This study revealed a high degree of combination of VR technology and digital conservation of the Fuliang Red Pagoda through virtual reality technology, which enhanced the overall authenticity of the virtual architectural heritage. In the process of restoring and displaying the building scenes of the Fuliang Red Pagoda, virtual reality technology is used to reconstruct its historical space and comprehensively preserve the authenticity of its historical information. Modern virtual reality technology provides more artistry to architectural heritage so that spatial artistry and historical authenticity are fully guaranteed [9]. Through the combination of virtual reality and digital animation systems, visitors can appreciate internal structures, paintings, sculptures, and other forms of art without having to access real historical heritage. This approach effectively reduces tourists' visiting time inside architectural heritage sites, especially during the peak season, and can effectively reduce the damage caused by human activities to architectural heritage sites, overcoming the contradiction between preservation and display [10,11].

2. Case Study

With the current status of ancient architecture in Fuliang County, Jingdezhen has a complex and rich historical and cultural heritage, showing the long history and unique cultural style of the area [12]. Located in Jingdezhen city, Jiangxi Province, Fuliang County is part of Jingdezhen, the ceramic capital of China, and its ancient architectural remains have a long history and unique cultural connotations. The ancient buildings in Fuliang County are mainly characterized by ceramic kiln sites and kiln remnants (Figure 1). These ancient kiln sites are not only relics of the ceramic culture of Jingdezhen but also important sites for the study of ancient Chinese ceramic technology and history [13].

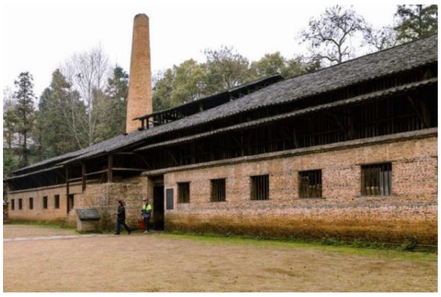

Figure 1. Jingdezhen Imperial Kiln Factory Site.

There are still some relatively well-preserved ancient buildings in Fuliang County, such as temples, monasteries, and ancient villages. Among them, the ancient building complex of Longwei Village is a more typical representative whose architectural style integrates the traditional architectural styles of Jiangnan and Han and is well preserved, showing the living atmosphere and architectural style of ancient Jiangnan villages. Fuliang Red Pagoda is a famous attraction in Jingdezhen Fuliang County and a local landmark. Opened to the public as a scenic spot, the Fuliang Red Pagoda (Figure 2) attracts many tourists. The Red Pagoda stands on the top of the mountain, towering into the clouds, with its green bricks and red tiles, solemn and beautiful modeling, showing the exquisite craftsmanship of ancient architecture and the charm of aesthetics. Visitors can climb the pagoda to look into the distance, enjoy the magnificent scenery of the county town of Fuliang, and experience a strong historical and cultural atmosphere. However, with the advancement of modernization and the acceleration of urbanization, ancient buildings in Fuliang County are facing certain pressure from the urbanization developments and the challenge of natural aging of the structures [14]. Ancient pagodas are facing the risk of gradual destruction and collapse due to their age and poor maintenance. At the same time, the destruction of the environment around some of the ancient buildings, development, and construction also caused certain difficulties in their protection [15].

Figure 2. The Red Pagoda of Fuliang.

The height of the Fuliang Red Pagoda is 37.80 m, with seven layers on eight sides and a base side length of approximately 20 m (the plane graph is shown in Figure 3), and the scale is magnificent. The pagoda bodies use large brick solids, and each layer has a brick-stacked picket platform and no hooks or rails. The pagoda body layers are equipped with a dark layer, and a staircase is built for people to ascend. The interior has a total of 14 floors. The structure of the hollow inner-body tube is adopted through the wall around the flat seat, which is a brick pavilion-type pagoda. Exterior and interior decorations using wood carvings, brick carvings, stone carvings, and other crafts are exquisite, showing the skill and art level of ancient craftsmen. Red Pagoda is one of the earliest, largest, and best-preserved ancient pagodas in Jiangxi Province and is known as "the first pagoda in Jiangxi Province". It is known as the "ancient city emblem" of Fuliang and is also a symbol of ancient Fuliang and a witness of history. The Red Pagoda embodies the architectural design of the Northern Song Dynasty's early period and showcases the artistic modeling features typical of that era, making it a unique fusion of traditional Chinese pagoda styles and the architectural elements distinctive to Jiangnan. Consequently, this pagoda stands as an invaluable resource for examining the local historical context of Fuliang County as well as the evolution of pagoda architecture.

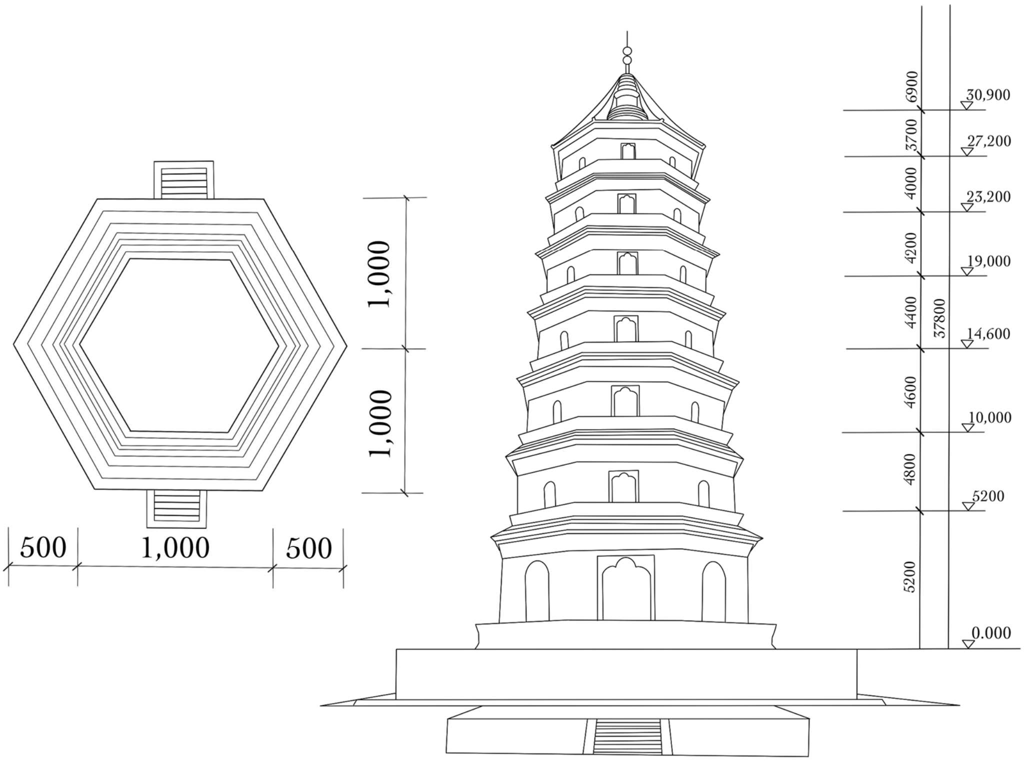

Figure 3. Plane graph of the Red Pagoda (cm).

While strengthening the repair, protection, and management of ancient buildings, it focuses on the organic combination of ancient buildings and modern urban construction so that it can inject new vitality into local economic and social development while protecting traditional culture. Therefore, digital protection and inheritance of the Red Pagoda architectural heritage in Fuliang County have become important among the key technologies for architectural heritage protection.

3. Data Acquisition Methods and Construction

3.1. Overall Approach to Model Construction

Point cloud data are a kind of dataset consisting of a large number of discrete points in three-dimensional space that can provide high-precision three-dimensional information (the processing flow is shown in Figures 4 and 5). Point cloud data can be acquired in a variety of ways, such as laser scanning, structured light projection, and photogrammetry, which are highly flexible and can be applied to a variety of scenarios with application requirements. In addition to position information, other attribute information, such as color, curvature, and normal direction, can be provided, which provides rich characterization and facilitates processing and in-depth analysis and is therefore suitable for multidisciplinary applications, such as engineering design, environmental monitoring, and physical identification.

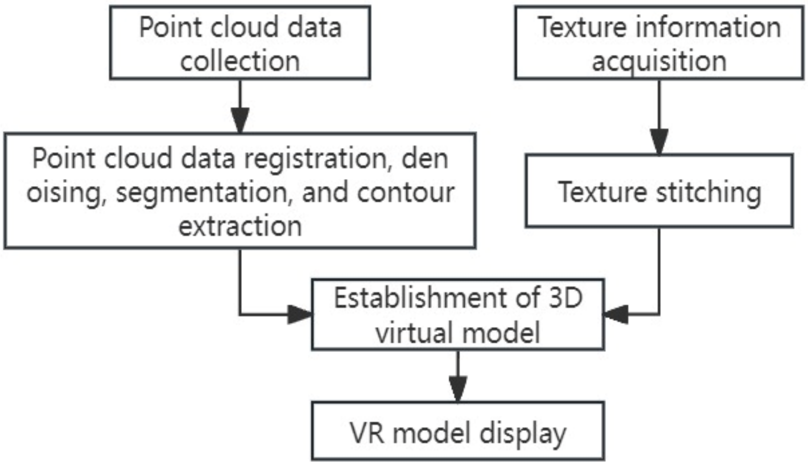

Figure 4. Data processing and modeling flow.

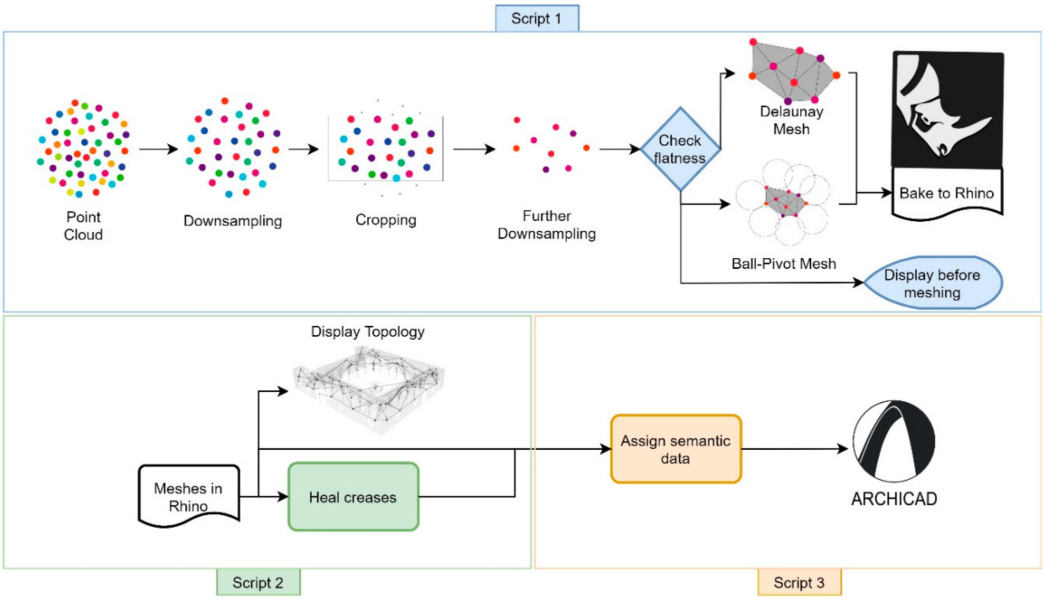

Figure 5. Automatic parameterization workflow [16].

As we can observe from the above diagram (Figure 5), the point cloud data model is more convenient and fast in dealing with 3D model objects and more realistic and delicate in creating virtual models; therefore, this study adopts point cloud technology to establish the VR model of the Red Pagoda building in Fuliang. This study first obtained the point cloud data of the Red Pagoda in Fuliang County through a 3D laser scanner and then imported the point cloud data into the computer for point cloud data alignment, point cloud data denoising, point cloud data segmentation, and extraction of the point cloud data outline [17,18]. Finally, the texture splicing is built into a 3D model to show the VR effect model [19].

3.2. Application Approach of VR Technology

Virtual reality (VR) technology, computer technology as a carrier, and virtual and real environments are combined to generate a simulated environment so that users can be in the virtual environment [20]. In virtual reality, the user can interact with the virtual environment and experience a feeling similar to that of the real world so that the user feels immersive. The composition of the VR system is shown in Figure 6.

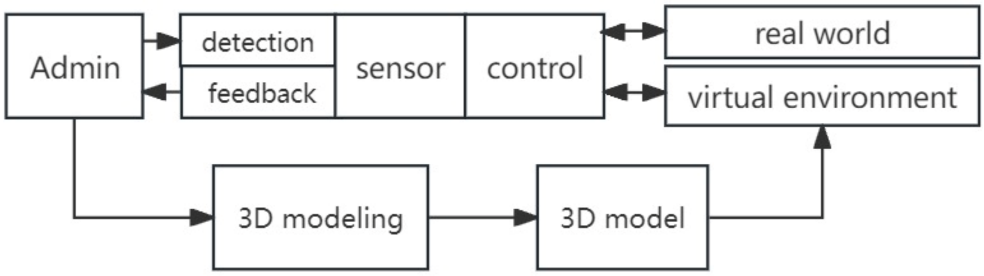

Figure 6. Composition of the virtual reality system.

In the virtual reality environment, through laser scanning and 3D modeling technology, the building is digitally preserved; the structure, details, and environment of the building can be effectively documented and protected [21]; the architectural heritage can be remotely monitored to detect and address potential problems and risks in a timely manner, preventing it from being damaged by natural disasters or other forms of human beings to achieve long-term preservation of the building.

3.3. Acquisition of Point Cloud Model Data

The data analysis technology of the study is mainly used to acquire the point cloud data of the Red Pagoda by scanning the target building via 3D laser scanning. This research utilizes the technical principle of laser ranging, a noncontact measurement system for the acquisition of large-area, high-density spatial three-dimensional data on the outside of the Red Pagoda, which is characterized by a high density of points in the acquisition space, a high precision of the measurement, and a high speed of the measurement. After the Red Pagoda scene is scanned with a 3D laser scanner, a large number and density of points can be obtained, and then these points are given 3D coordinates to create a recognizable 3D model of the Red Pagoda [22]. The spatial coordinates of the 3D laser scanner are shown in Figure 7.

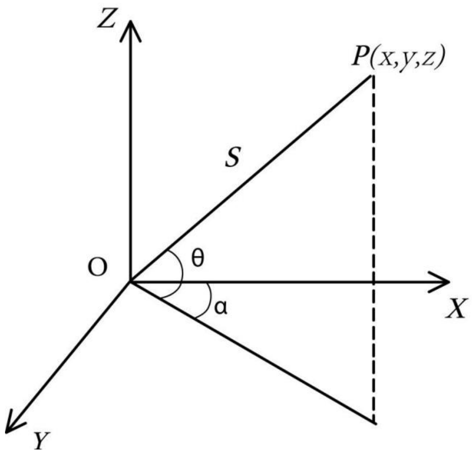

Figure 7. Schematic diagram of the spatial coordinate principle of the 3D laser scanner.

Assuming that the distance to the object obtained from ranging is S, the longitudinal angle of the object to be measured is θ, and the transverse angle is α, from which the coordinates of the 3D laser footpoint $P(XS, YS, ZS)$ and the relative coordinates of the coordinate origin can be obtained by the following formula:

$$\begin{cases} X = S\cos\theta\cos\alpha \\ Y = S\cos\theta\sin\alpha \\ Z = S\sin\theta \end{cases} \tag{1}$$

First, we conducted a field survey of Red Pagoda in Fuliang County to obtain survey data for the site and the building, and then we collected the point cloud data as well as the texture information.

The data collection process is composed of two main processes: preparation and scanning. In the preparation stage, it is necessary to carry out field surveys according to the geographical location of the Red Pagoda and environmental conditions to design and arrange a three-dimensional instrument scanner. When installing a laser scanner, the scanning area, scanning resolution, laser power, and other parameters need to be set to avoid interference from noise to facilitate subsequent measurement processing [23].

In the scanning phase, due to the complexity of the acquisition target, to acquire the whole building, it is necessary to scan from different angles and ensure that the overlap of data acquisition at each scanning site is approximately 30%. As shown in Figure 8 (△ is the position of the instrument), the building data are acquired. In the process of data acquisition, because the pagoda is too high and often affected by factors such as occlusion and light, four additional scanning sites are set up at a distance to prevent the existence of scanning blind zones. When the laser beam intersects the surface of the target object, part of the laser energy is reflected and received back into the laser scanner, which is used to calculate the distance and position of the reflected points. By measuring the time of the laser pulse from emission to reception, the propagation time of the laser in space was calculated to determine the distance of the reflection point. The final data obtained from the scan are given in Table 1.

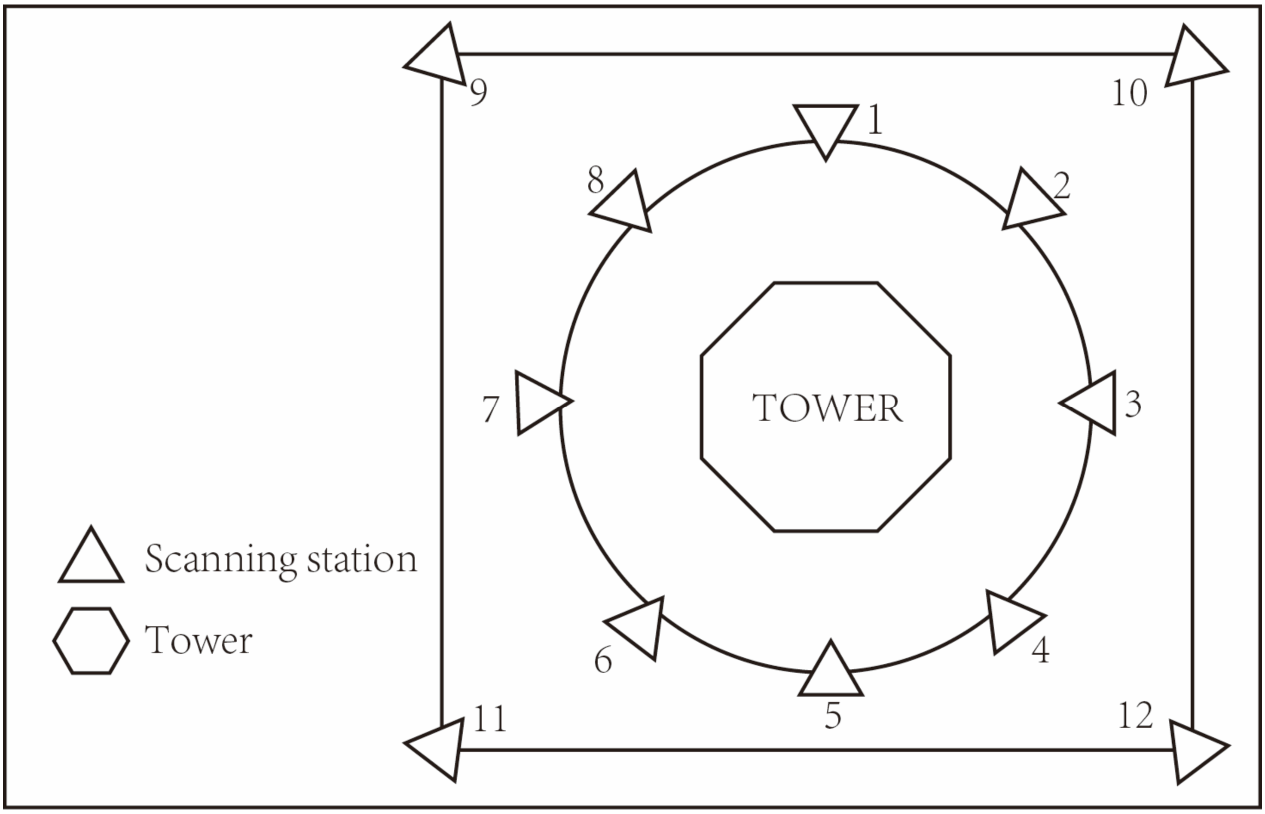

Figure 8. Schematic diagram of the scanning point arrangement.

Table 1. Scanning data.

Station	Distance (m)	Scanning Time	Point Count	Surface
1	20.5	5 min 14 s	457,824	749,238
2	21.3	5 min 7 s	325,244	694,837
3	20.1	7 min 4 s	434,245	712,042
4	19.9	6 min 46 s	456,331	722,340
5	21.4	5 min 45 s	398,372	642,954
6	19.8	5 min 23 s	412,050	682,348
7	18.9	7 min 13 s	364,913	524,343
8	20.3	6 min 39 s	423,421	542,344
9	28.5	10 min 25 s	654,646	942,342
10	27.9	9 min 13 s	576,576	843,687
11	26.9	9 min 47 s	589,797	899,433
12	28.2	8 min 54 s	627,395	862,948
Total			5,720,814	8,818,856

3.4. Texture Information Acquisition

The effect of texture material also has an important role in the display of VR effects; the use of materials closer to the reality of the original material strives to achieve the same effect as reality, thus enhancing the experience of VR effects.

Since point cloud data have no color, modeling based on point cloud data alone is not intuitive, and it is necessary to determine the surface texture characteristics. To obtain accurate texture information, it is necessary to utilize high-resolution imagery. This involves acquiring photographs that encompass both the entirety of the building's facade and its intricate features, ensuring a comprehensive visual record for analysis. Then, these images are aligned with the point cloud data to ensure that the images are spatially aligned with the point cloud. Next, the image information is mapped onto the corresponding point cloud via texture mapping. Finally, through rendering, the processed point cloud model is displayed in combination with the texture information so that accurate building texture acquisition can be realized (as shown in Figure 9).

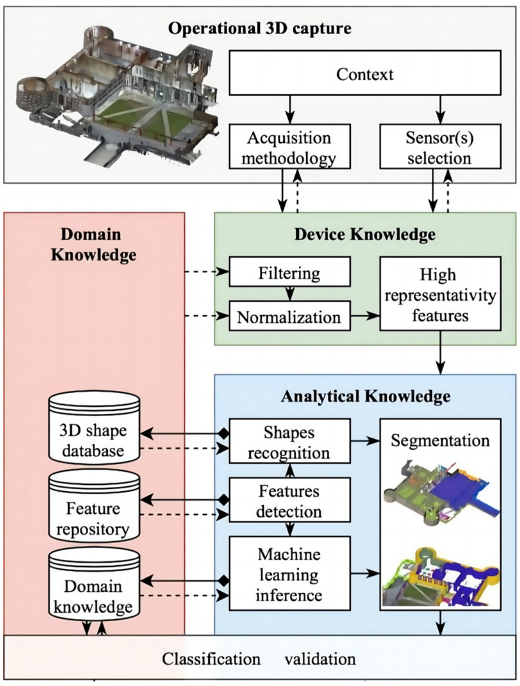

Figure 9. Derived from the Smart Point Cloud [24].

4. Red Pagoda Point Cloud Data Processing

After the data information has been collected, the data processing process begins, and the data are converted into the graphic data of the building. The processing of point cloud data mainly includes the process of data alignment, data denoising, data segmentation, and data contour extraction.

4.1. Perform Point Cloud Data Alignment

Data alignment, also known as data splicing, is the most important part of point cloud data processing, and the accuracy of data alignment is directly related to the results of data processing. Due to the limitations of scanning instruments and measurement methods, there may be data at different times and from different viewpoints, so there is a certain deviation; hence, it is necessary to carry out multiple local scans to obtain multiple local point clouds [25].

To obtain a more complete and accurate building data model, it is necessary to process each local point cloud and merge it into a coordinate system with a unified spatial position and direction so that it can be easily visualized and applied via point cloud data alignment. To ensure the accuracy of the data as much as possible, in the process of data alignment, it is also necessary to carry out splicing several times, check the profile of the data, and modify the data with large errors [26]. For the characteristics of the pagoda, it is necessary to collect multiple point cloud data from different angles or heights, so data alignment is very important, and the algorithm used is iterative closest point (ICP), which can obtain a unified coordinate system of the Red Pagoda building model, avoiding overlapping or misalignment. ICP is an iterative optimization algorithm that is suitable for optimizing point cloud data in two sets of point clouds [27]. It is suitable for finding the most suitable rigid transformation in two sets of point cloud data and aligning them as much as possible, as shown in Figure 10.

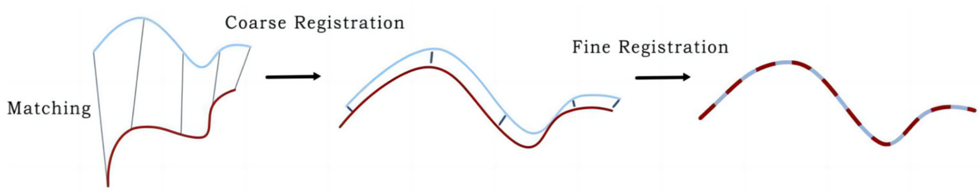

Figure 10. ICP algorithm flowchart.

The specific steps for data alignment are as follows:

Assuming two sets of point cloud data, one is the target point cloud P and the coordinates of its feature points are $X_{1i}(x_{1i}, y_{1i}, z_{1i})$. The other group is the source point cloud Q, and the coordinates of its feature points are $X_{2i}(x_{2i}, y_{2i}, z_{2i})$ and $i \in [1, n]$. The alignment principle is shown in Figure 11.

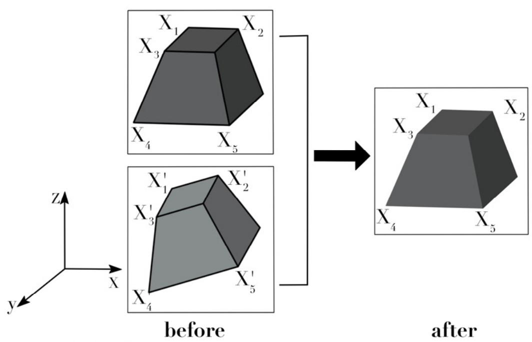

Figure 11. Principle of ICP alignment.

Initially, a transformation T is set, which will be gradually adjusted in subsequent iterations. The following steps are repeated, knowing that convergence or the maximum number of iterations is reached:

The center of gravity of the target point cloud P and the source point cloud Q are calculated as follows: $\overline{X}_1$ and $\overline{X}_2$

$$\left.\begin{array}{l} \overline{X}_1 = \frac{1}{n}\sum\limits_{i=1}^{n} X_{1i} \\ \overline{X}_2 = \frac{1}{n}\sum\limits_{i=1}^{n} X_{2i} \end{array}\right\} \quad (2)$$

Decentering:

$$\hat{X}_{1i} = X_{1i} - \overline{X}_1, \hat{X}_{2i} = X_{2i} - \overline{X}_2 \quad (3)$$

Calculate the transformation matrix: By the least squares method, the rotation matrix R and the translation vector t can be obtained by using the transformation matrix T:

$$T = \begin{bmatrix} R & t \\ 0 & 1 \end{bmatrix} \quad (4)$$

Apply the transformation: Apply the transformation Q to the source point cloud T to obtain the new source point cloud Q'.

$$X_{2'i} = RX_{2i} + t \quad (5)$$

Update transform: Multiply T by the currently obtained transform matrix:

$$T \leftarrow T \cdot T' \quad (6)$$

In the above steps, T' is the transformation matrix calculated in each iteration, and the iterative process gradually aligns the target point cloud P with the source point cloud Q, which needs to be adjusted according to the specific situation in the actual application.

4.2. Perform Point Cloud Data Denoising

Data noise refers to the irrelevant or unwanted interference signals or errors generated in the data because of unavoidable external interference factors such as ambient light and personnel operation during data measurement, resulting in the inability of the data to accurately represent the position of the measurement object [28]. The purpose of data denoising is, first, to improve the data quality and accuracy, reduce the amount of memory space occupied, and second, to make the point cloud more consistent with the geometry of the actual architectural scene and minimize the impact of noise on the subsequent processing of the data [29]. Denoising also includes software denoising and manual denoising. The software can set a threshold to achieve automatic denoising, and after software denoising, manual denoising is needed. Some invalid point cloud data cannot be recognized, and the data need to be manually processed. There are a large number of trees, vegetation, or other buildings around the pagoda, which will produce occlusion or noise points. The denoising operation can use a filtering algorithm to remove these interference points, making the point cloud data of the Red Pagoda cleaner and clearer, retaining the real contours and details of the pagoda, and making the model clearer and more reliable. The denoising processing method is shown in Figure 12.

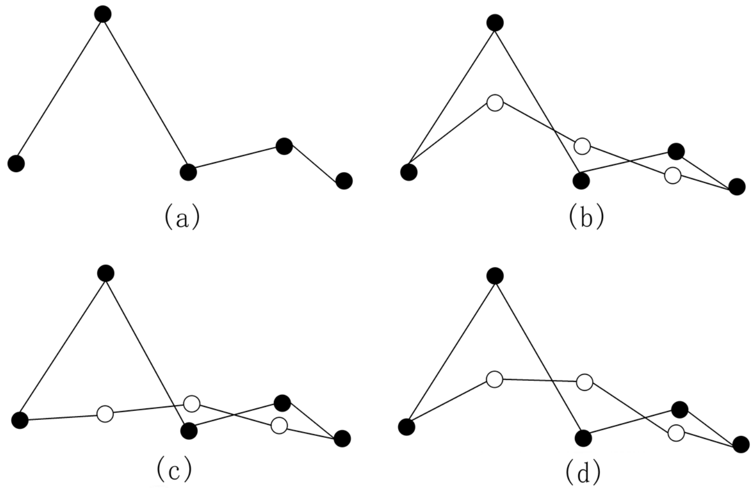

Figure 12. Filter processing denoising schematic diagram. (**a**) Original data. (**b**) Gaussian filter processing. (**c**) Mean filter processing. (**d**) Median filter processing.

4.3. Perform Point Cloud Data Segmentation

When dealing with a large amount of data point cloud data, it will be difficult to process them at the same time, so the point cloud data will be partitioned accordingly and divided into a number of blocks for easy operation and modeling (as shown in Figure 13). Then, each block will be processed separately and finally merged [30]. This approach can not only facilitate the operation but also ensure that no detailed information is overlooked and can also improve the accuracy of modeling to obtain a more realistic 3D model. The building includes the pagoda body, pagoda top, pagoda base, and other parts, and point cloud data segmentation can separate these different parts; for example, segmentation of the pagoda body and pagoda top point cloud data can be modeled and measured separately for these parts, which can help subsequent analysis of the building or visualization of the display for historical restoration and protection to provide important information. Data segmentation can be performed using the region-growing algorithm [31].

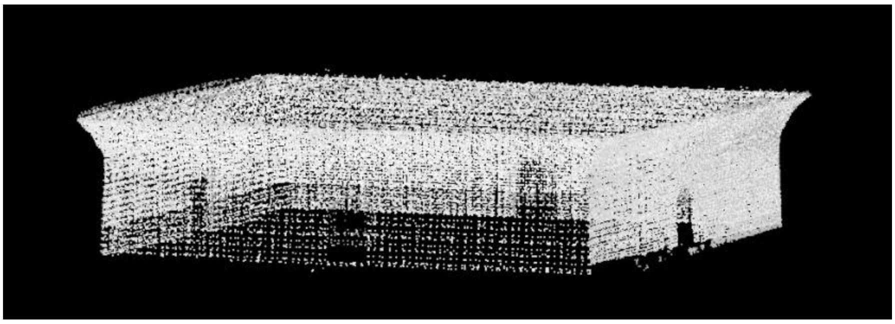

Figure 13. Effect of local point cloud block segmentation.

The researcher of this project used the region growing method for data segmentation, which usually uses Euclidean distance to measure the similarity between points with the following formula flow:

The Euclidean distance between two points is calculated with the following equation:

$$D_{ij} = \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2 + \left(z_i - z_j\right)^2} \quad (7)$$

where (x_i, y_i, z_i) and (x_j, y_j, z_j) denote the coordinates of two points in the point cloud.

Similarity judgment: In the process of region growth, for each seed point P_s, the condition for determining whether the neighboring point P_n belongs to the same region is $D_{sn} < T_{th}$.

Where D_{sn} denotes the Euclidean distance between the seed point P_s and the neighboring point P_n, and T_{th} is the similarity threshold, which indicates that two points are considered to belong to the same region when the distance between them is less than the threshold.

The conditions for growth are defined as follows: a seed point P_s is chosen as the starting point. The neighboring points P_n of the seed point P_s are iterated, and their distances from the seed point D_{sn} are calculated. If $D_{sn} < T_{th}$, P_n is added to the region where the seed point P_s is located, P_n is set as the new seed point, and the process is continued.

Repeat the above iterative process. If there is no neighboring point P_n that satisfies the condition, then the current region growth is completed, and a new seed point is selected to continue the region growth.

4.4. Perform Point Cloud Data Contour Extraction

Being the Red Pagoda a building with unique shapes and contours, its external contour lines are very important for the expression and visualization of the building features. Through point cloud data contour extraction, the contour lines of the building can be accurately captured, which helps to generate 2D contour maps of the building or edge lines for 3D models. Metrics such as curvature or normal change can be used to identify the edge points, and then, contour line extraction operations can be performed for building morphology analysis, comparison, and presentation [32]. Considering the irregularity of the building façade, conventional algorithms cannot collect contours. To obtain accurate contours, the data obtained from point cloud data segmentation are used to extract the data contours in blocks and regularize and process the contour lines. Then, the individual block contours are composed into a complete model (Figure 14), which improves the modeling efficiency while enhancing model accuracy.

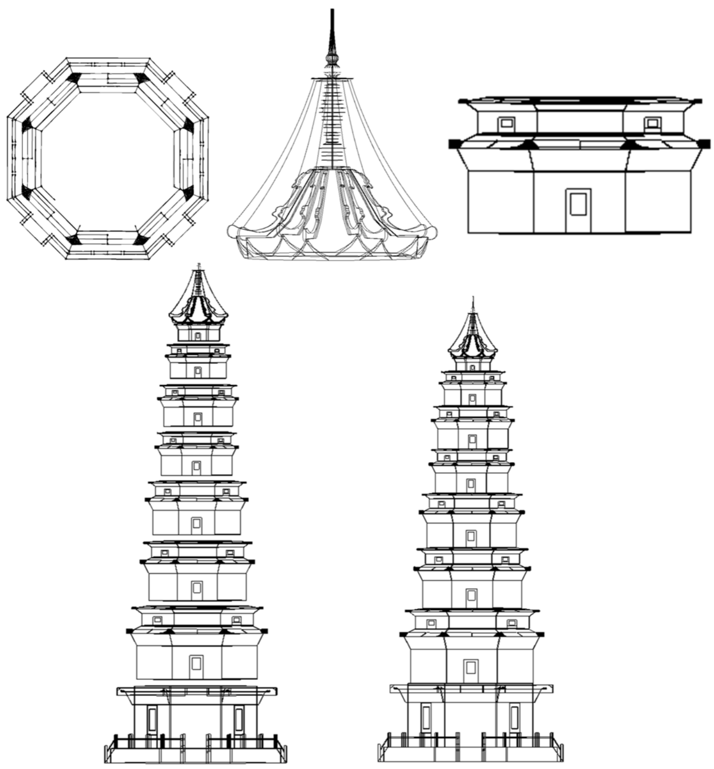

Figure 14. Local building outline extraction and synthesis.

5. Results

5.1. Establishment of Virtual Modeling of the Fuliang Red Pagoda

First, we need to choose the appropriate modeling software. This project uses SketchUp software (https://www.sketchup.com/en, accessed on 12 May 2024), which has a wealth of modeling tools and functions that can help us accurately build the architectural virtual model of the Red Pagoda. The contour data extracted from the point cloud are saved in skp format through the plug-in and imported into SketchUp software to transform the data into a virtual model. First, the imported point cloud data are aligned with the origin and axis of the model, and then, lines and building model contour lines are manually drawn based on the basic shape of the point cloud contour. After extracting the contour lines, for pagoda buildings, we can start modeling from the basic geometry and gradually add and adjust the model details according to the structural characteristics of the Red Pagoda. For example, by drawing and adjusting the polygonal curves to simulate the masonry structure of the Red Pagoda, the carving of the eaves, etc., the modeling is made closer to the actual building. Special attention is given to the unique decorations and detailed carvings of Red Pagoda's architecture, as well as the special shape of the top of the pagoda, which makes the modeling more realistic and fine. After that, according to the material characteristics of Red Pagoda, the appropriate material properties are set, the appropriate textures and materials obtained from the collection are added, the complete model is constructed, and after the modeling is completed, the checking and correction of the model are carried out. Whether the model conforms to the scale, structure, and details of the actual Red Pagoda is checked, and necessary adjustments and corrections are made. Finally, the 3D model of the building is exported to 3D model format for use and display in different software platforms or scenes to establish the virtual model of the building, as shown in Figures 15 and 16.

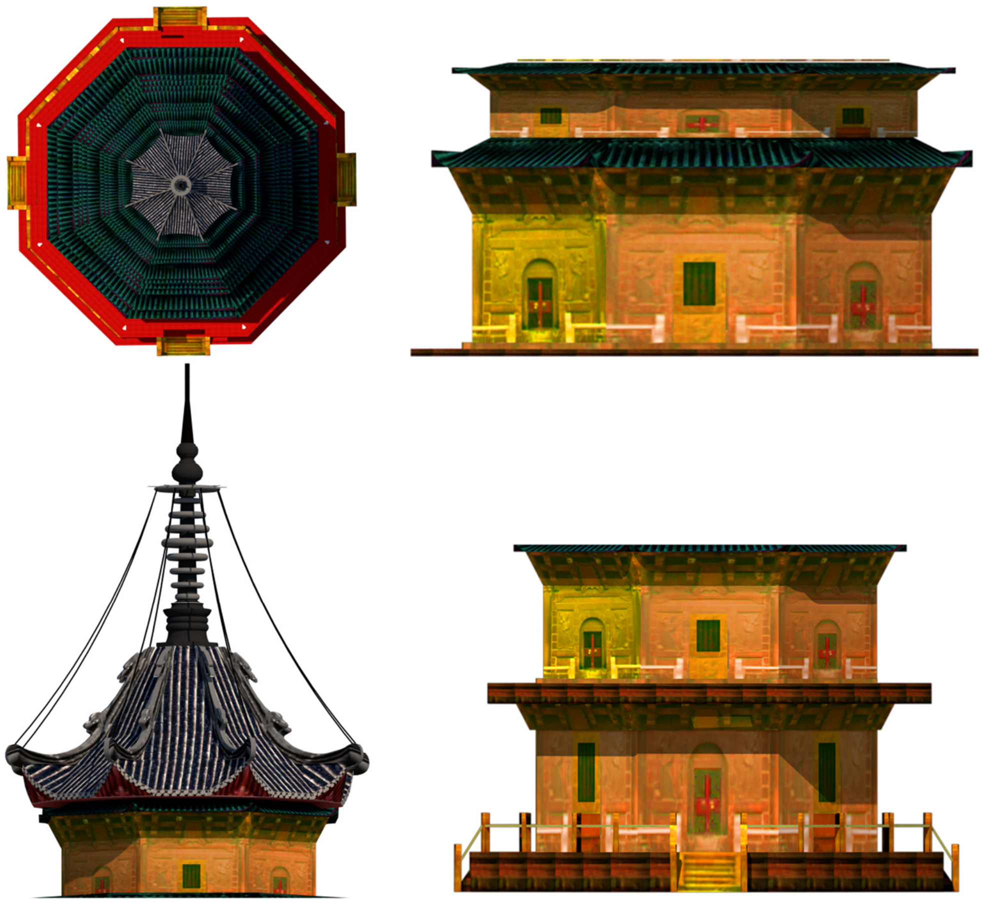

Figure 15. Local effect drawing.

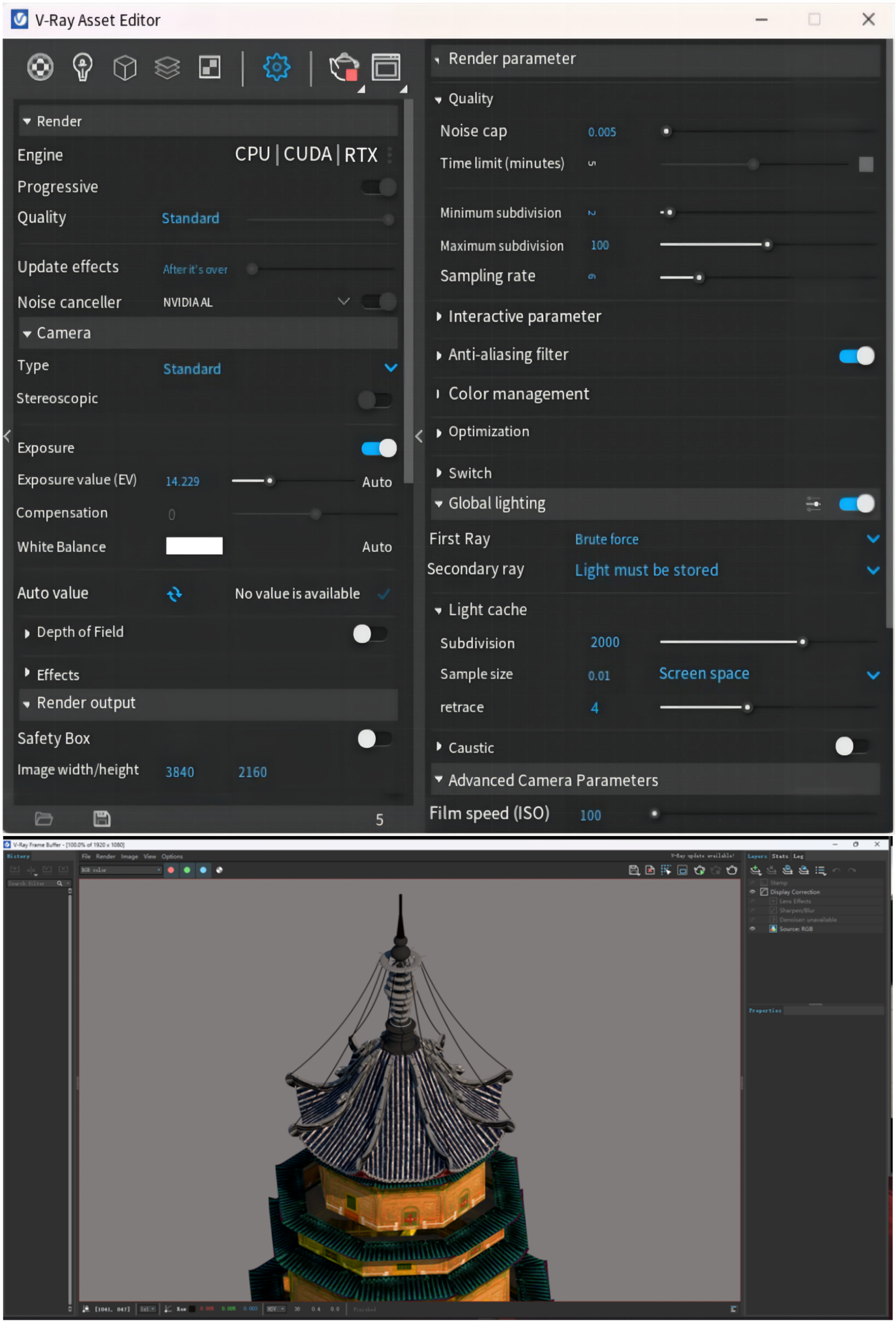

Figure 16. The modeling software operation interface (V-ray 6.1).

After modeling, the architectural details of the ancient pagoda can be infinitely enlarged and reduced, allowing the form of the architectural structure to be well displayed. This process has also successfully restored the architectural structure and form of the ancient pagoda, as shown in Figure 17.

Figure 17. Comparison between the current state of the building and the virtual model.

5.2. VR Effect Display of Fuliang Red Pagoda

The 3D model of the building is realized as a VR display on the computer (as shown in Figure 18). In the VR environment, the relevant building information can be viewed in real time from multiple directions, multiple viewpoints, and dynamic interactive browsing, which intuitively and clearly shows the overall flatness of the building and can be operated online [33]. In addition, with the help of other interactive programs, more operation methods can be developed, such as realizing the decomposition, movement, and splicing of building components, which can effectively restore the structural characteristics and texture information of Fuliang Red Pagoda, minimize architectural damage residual damage, and realize the digital protection of ancient architectural heritage.

Figure 18. Rendering of the Red Pagoda in VR.

6. Discussion

The application of virtual reality (VR) technology in the field of cultural heritage protection has become a trend. Through VR technology, people can experience and protect cultural heritage in a more intuitive and immersive way, realizing a new breakthrough in cultural heritage and protection [34]. This study takes the digital heritage protection work of the Red Pagoda of Fuliang as an example and adopts virtual reality technology for protection and display. The digital architectural heritage protection technology supported by VR technology mainly contains the following three core technologies:

a. Three-dimensional scanning technology: The use of laser scanning and other technologies to carry out a complete three-dimensional scanning of various architectural details, pattern textures, etc., to obtain detailed digitized data of the Fuliang Red Pagoda.
b. Virtual reconstruction: According to the data obtained from three-dimensional scanning, virtual reality technology is used to carry out digital modeling and digital reconstruction of the Fuliang Red Pagoda, accurately restoring the original architectural appearance of the Fuliang Red Pagoda.
c. Interactive experience: To develop interactive VR applications, users can interactively experience the architectural beauty of the Fuliang Red Pagoda through VR equipment, strengthen the free exploration of the digital architectural model of the Fuliang Red Pagoda based on VR technical support, and enhance the sense of interactive experience of the digital architectural model.

Through the above three core technologies, it is not difficult to determine that digital heritage preservation under the intervention of VR technology has become one of the key technologies of heritage preservation, which is mainly reflected in the following three points.

First, VR technology advances the digital protection of architectural heritage. Through virtual reality technology, the Fuliang Red Pagoda is digitally preserved, avoiding further damage caused by time and environmental changes. Second, VR technology effectively enhances the sensory experience: Users can take an immersive tour of the Fuliang Red Pagoda through VR equipment and enjoy its magnificent architecture, exquisite sculptures, and deep historical heritage, enhancing the feeling of cultural heritage inheritance. Finally, VR technology expands the communication channels of architectural heritage, utilizing virtual reality technology to spread the cultural heritage of the Fuliang Red Pagoda around the globe, so that more people can understand and give value to the protection of the Chinese architectural heritage. Meanwhile, through this case study of VR technology and digital architectural heritage protection, we can see the great potential of virtual reality technology in digital cultural heritage protection, and VR technology will bring more innovative development opportunities and market promotion conditions for the protection and inheritance of architectural cultural heritage [35].

7. Conclusions

This study discusses the application value and key technology of VR technology in the protection of architectural heritage, takes the ancient architectural relic of Fuliang Red Pagoda in Jingdezhen, Jiangxi Province, as the research object, and discusses in depth the digital protection process of ancient architectural heritage based on VR technology through the data acquisition, analysis and processing of Fuliang Red Pagoda, the establishment of a three-dimensional geometrical model, the formation of the VR display effect of Fuliang Red Pagoda, and other steps. The results of the study show that VR technology is highly adaptable for the protection of ancient architecture, with a high degree of restoration, realistic detailing, and other performance effects; the maximization of effective digital restoration and repair without changing its original form; the realization of digital protection of ancient architectural heritage; and the provision of a new research perspective and technical method for the protection of architectural heritage.

The current digital protection of ancient architectural heritage has not yet been popularized, and there are still some gaps in mature systematic digital protection methods. At the same time, there are still some deficiencies in the hardware facilities and technical means of scanning technology used in the study, such as the possibility of using professional imaging drones and software to obtain architectural node data information and other technical means that need to be explored and practiced, which is the next step in the study to continue to deepen the direction of the study and research.

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