# Design of an Architectural Heritage Visualization System Based on Cesium

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**Abstract**

Amid rapid global urbanization, architectural heritage preservation faces challenges like high resource consumption, low efficiency, and poor information visualization. Traditional methods, with heavy human, material, and financial investments, fail to fully present heritage details via archives, unable to meet large-scale, precise conservation needs. To address this, this paper develops a visual digital platform for architectural heritage protection through secondary development of the Cesium framework, integrating WebGIS, Node.js, Vue, and MySQL. The platform enables full-life-cycle management of heritage data, supports multi-source heterogeneous data upload and efficient management, and presents 3D visualized heritage models for an immersive experience. Innovatively incorporating GIS analysis (distance measurement, area calculation, coordinate picking), it provides data support for conservation decisions. It also allows uploading metadata (CAD drawings, videos, PDFs), forming a "3D model + materials" digital management system to enhance solution integrity. Verified with Xingcheng Ancient City as a case study, the platform offers a new approach for digital preservation and efficient management of architectural heritage, boosting the digitalization and technical application in heritage protection.

## 1. Introduction

Architectural heritage is not only the spiritual symbol of a nation but also the material embodiment of human historical culture (Agapiou et al., 2015). Therefore, the protection of architectural heritage is extremely urgent. However, traditional methods for protecting architectural heritage require substantial resources to collect location information, attribute information, and historical and cultural information of architectural heritage. These materials on architectural heritage often take paper archives as carriers (Chabowski et al., 2011). Although they have the value of first-hand documents and literature, there are excessive documentary materials, which are difficult to integrate, as shown in Figure 1. There are significant limitations in information presentation and information dissemination. In addition, it is restricted by the two-dimensional plane expression form (Chatzigrigoriou and Mavrikas, 2014), making it difficult to completely present the spatial topological relations, geometric texture construction details, and detail evolution trajectories of architectural heritage (Figure 2).

Figure 1. Paper documents

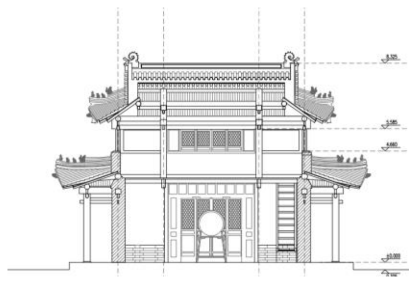

Figure 2. Two-dimensional drawings

In the era of the global digital wave, in the face of massive information on architectural heritage, the traditional protection methods of architectural heritage mentioned above are inefficient in sorting, storing (Inkpen et al., 2008), or retrieving relevant data. They cannot meet the public's needs for all-around and immersive experience tours of architectural heritage, and it is more difficult to adapt to the characteristics of cross-regional and cross-cultural communication in the information age. In addition, traditional paper document records cannot dynamically monitor and update architectural heritage in real time, nor can they effectively archive the changes of architectural heritage. Therefore, constructing a visual digital platform for architectural heritage has become an effective solution in the field of architectural heritage protection.

Currently, both Threejs and Cesium are widely used visualization platforms. Threejs is a lightweight JavaScript library suitable for the display and development of small-scale 3D scenes. It features a highly flexible rendering mechanism, enabling rich presentation of special effects and detailed interactive effects for small 3D models (Li, 2019). However, it lacks geospatial data processing capabilities, making it difficult to integrate massive and large-scale geographic information.

This poses challenges when handling the geospatial distribution information of architectural heritage.

Cesium, a WebGL-based virtual globe and earth visualization engine, efficiently loads global geospatial data, supports the loading of various map interfaces, and enables 3D terrain visualization (Figure 3). Thus, it has advantages in displaying the geographic locations of architectural heritage and analyzing their spatial distribution. Additionally, Cesium supports multiple data formats, smoothly docking multi-source and heterogeneous data, and perfectly presents comprehensive scenarios such as the locations of architectural heritage, their 3D models, and surrounding topographic and geomorphic information.

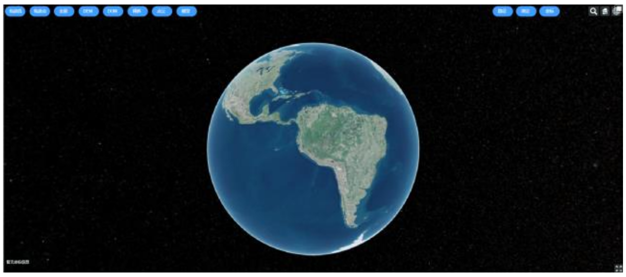

Figure 3. Cesium visualizing earth

However, despite its advantages in displaying comprehensive scenarios and geographic distributions, Cesium still has limitations in visualizing architectural heritage:

First, it lacks native GIS analysis functions (e.g., common GIS operations like distance measurement, area calculation, and height difference calculation), failing to meet users' needs for acquiring geometric data from 3D models in architectural heritage protection. To implement these functions, integrating GIS tools or secondary development based on Cesium is required. Then, Architectural heritage often contains abundant attribute information (e.g., age, materials, etc.). Cesium has obvious limitations in processing such business logic data—the native framework struggles to efficiently organize and handle this data. Therefore, when constructing a visual digital platform for architectural heritage, system architecture redesign and functional integration are necessary.

This paper conducts secondary development based on the Cesium framework to build a visual digital platform that meets the application requirements of architectural heritage protection. The platform realizes full-life cycle management of architectural heritage data (Hu et al. 2020), supports the upload and efficient management of multiple heterogeneous data, uses 3D visualization technology to display the detailed features of architectural heritage models, and provides users with an immersive experience. To meet the needs of managers for geometric measurement of architectural heritage, the platform innovatively integrates GIS analysis functions, enabling operations (Li et al., 2020) such as distance measurement, area calculation, and coordinate picking—providing effective data support for managers to make decisions on architectural heritage management.

Different from traditional visualization platforms, this visual platform has achieved innovative breakthroughs in the following aspects:It extends the functions of architectural heritage models. Beyond mere visualization, it enables GIS analysis operations, significantly improving the management efficiency of managers. And it supports the upload of metadata resources such as CAD drawings, video materials, and PDF documents, realizing a digital management system of "3D model visualization + related materials." This innovative architecture not only enhances the integrity of architectural heritage protection management solutions but also provides a new solution for architectural heritage protection, greatly improving the digital level and technical application depth of architectural heritage protection work.

## 2. Related Work

### 2.1 The Current Status of Visualization Systems for Architectural Heritage

Since the end of the 20th century, paper-based documentation of architectural heritage has gradually transitioned to informatization and digitization. Visualization technologies such as virtual reality have also slowly enabled the digitization of architectural heritage. For example, at the 1995 Bath Virtual Heritage Conference in the UK, the public could view architectural heritage data models through special devices; in 1997, the EU incorporated the digital recording of cultural heritage into the blueprint of the "Second Development Stage" of the Information Society.

In the 21st century, the digitization of architectural heritage has flourished globally. Internationally, many countries and regions have actively carried out relevant digitization work. Among them, Italy has achieved remarkable results in the field of architectural heritage digitization (Radanovic, et al., 2020), and its scholars have conducted in-depth research on Historical Building Information Modeling (HBIM) and structural monitoring. For instance, in the protection of the Baptistery of San Giovanni in Italy, BIM modeling technology was used to achieve precise recording and analysis of the building's structure and space. In China, numerous important projects have been launched one after another. In the past three years, Harbin has completed the digital information collection, surveying, mapping, and filing of nearly 600 important historical and cultural buildings, achieving "digital twins". It has used technologies such as laser scanning and 3D modeling to construct 3D data models, providing a basis for precise protection, renovation, and active utilization. Since 2014, Shanghai has initiated the compilation of "one building, one file" protection archives for excellent historical buildings. The Excellent Historical Building Protection Management Information System launched in 2024 uses digital twin technologies such as GIS and 3D modeling to build 3D digital application scenarios, empowering building management. It is also connected to the joint review platform to improve the approval efficiency of renovation projects.

However, there are still some problems in the current digitization of architectural heritage. Although a large number of architectural heritage sites have undergone 3D laser scanning or photogrammetry, their subsequent research and utilization are insufficient, mostly staying at the level of simple preservation and display. The historical paper archives, promotional videos related to the architectural heritage, and 3D models have low correlation (Restuccia, et al., 2011), making it difficult to meet the actual needs of management departments for the systematic analysis and management of multi-source data on architectural heritage.


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### 2.2 Cesium-based 3D Model Loading Technology

As a powerful open-source framework for 3D globe visualization, Cesium demonstrates remarkable technical advantages in the field of digital display for ancient architectural models. Aiming at the diversified characteristics of ancient architectural model data formats, Cesium supports efficient conversion of common 3D model formats such as FBX, OBJ, and OSGB. Through the official open-source data processing software CesiumLab, original model data is uniformly converted into lightweight 3DTiles format, with the conversion process shown in Figure 4.

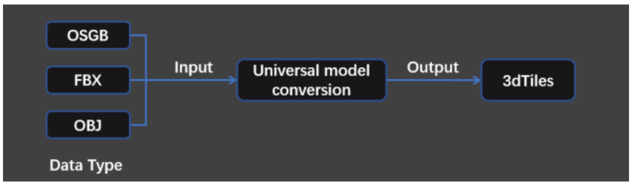



Figure 4. Conversion process

3DTiles is an open standard specifically designed by Cesium for large-scale 3D scene rendering. It adopts a tiling storage and loading strategy, splitting huge ancient architectural models into multiple small tile units to achieve "on-demand loading and progressive rendering" (Figure 5). This technology not only significantly reduces memory usage but also notably improves rendering efficiency. Even for ancient architectural models with complex structures and rich details, it can smoothly present them on web or client sides, bringing users a delicate and realistic immersive visual experience. Meanwhile, it provides solid technical support for the digital protection, remote monitoring, and cultural dissemination of ancient buildings.

(a) (b)

Figure 5. Layer-by-layer loading

### 2.3 Differences Between this System and Existing Work

The system has implemented geometric measurement functions for 3D models, covering core operations such as distance measurement, area calculation, height difference computation, and coordinate picking, enabling precise acquisition of spatial data. Meanwhile, it has completed the component-based decomposition of 3D architectural models. Through mouse interactions, users can view attribute information of individual components, including construction age, material type, repair history, etc., enhancing the refinement of architectural heritage management.

In terms of current model performance optimization, an efficient scheduling mechanism has not yet been implemented to accelerate loading speed, and the index partitioning of model tiles still needs to be reoptimized.

## 3. Methodology

### 3.1 Module Division

The system is primarily divided into the following three major modules, with the functions of each module as follows (Figure 6):

**Data Layer:** As the foundation of the system, the Data Layer is responsible for storing and managing multi-source heterogeneous data related to architectural heritage. On one hand, it supports the loading of 3D model data, accommodating the storage of ancient architectural models in various formats such as FBX, OBJ, and OSGB. These models are uniformly processed into 3DTiles format suitable for Cesium rendering through CesiumLab, ensuring efficient loading and display. On the other hand, it integrates associated materials, including MP4 video files, PDF documents, and panoramic image data, comprehensively recording the historical, structural, and environmental information of architectural heritage. The data storage employs a MySQL database, leveraging its robust structured data management capabilities to achieve efficient data storage, retrieval, and maintenance, providing stable data support for upper-layer services.

**Service Layer:** The Service Layer is built based on the Express framework and Node.js, fully utilizing the asynchronous I/O and event-driven characteristics of Node.js, combined with the lightweight and flexible advantages of Express for Web application development to achieve rapid response and efficient services. This layer receives requests from the Application Layer, processes and distributes architectural heritage data from the Data Layer—including conversion and transmission of 3D model data, scheduling and management of associated materials—and provides data interfaces to ensure smooth data interaction across layers. Through modular design, the Service Layer can quickly expand functional modules to meet subsequent system iteration needs, ensuring stable and efficient operation.

**Application Layer:** The Application Layer takes the Cesium and VUE frameworks as core to construct an intuitive and interactive user interface. Cesium provides powerful 3D globe visualization capabilities, supporting the rendering of global map imagery data to offer a realistic geographic spatial context for architectural heritage. Combined with the converted 3DTiles-format ancient architectural models, it achieves high-precision and immersive 3D display effects. The VUE framework handles user interaction logic, leveraging its efficient reactive data binding and component-based development model to quickly respond to user operations, such as model browsing, GIS analysis (distance measurement, height measurement, area calculation), and viewing of associated materials. Meanwhile, VUE's concise syntax and flexible component design ensure the Application Layer interface is simple and aesthetically pleasing, delivering a smooth operational experience for users and realizing visual and interactive display of architectural heritage data.

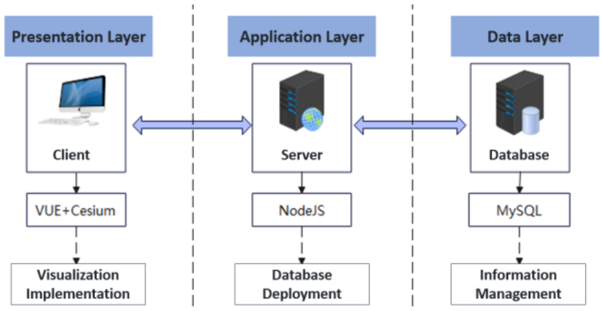



Figure 6. Main modules and functions of the system

### 3.2 Development and Application of GIS Functions

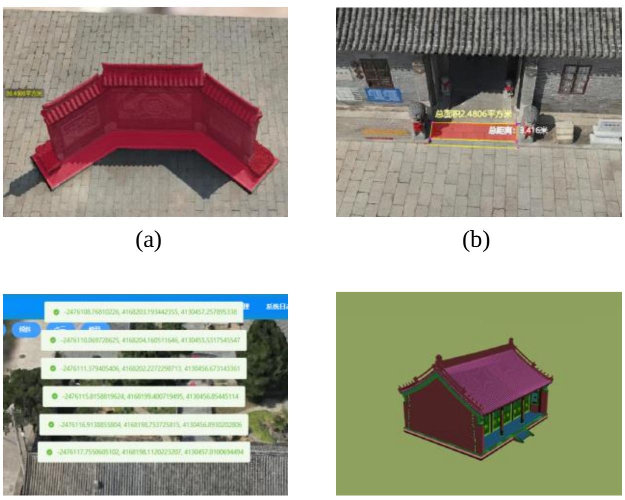
This research developed a series of GIS functions tailored for architectural heritage visualization platforms using the Cesium framework and JavaScript. By writing custom algorithms and interaction logic in JavaScript, we deeply integrated Cesium's 3D rendering engine and spatial analysis APIs to achieve efficient functionality, as shown in Figure 7 below.

(a) Area Marking Function: Leveraged mouse event listeners to capture coordinate sets of user-drawn regions. Used Cesium's geometry library to construct polygon entities with highlighted materials, enabling intuitive annotation of key heritage protection areas.

(b) Distance & Area Measurement: Retrieved 3D scene coordinates through screen picking, converted them to geographic coordinates using Cesium's ellipsoidal geodetic algorithms, and computed linear distances or polygonal areas. This provides quantitative data for heritage surveying and conservation planning.

(c) Coordinate Picking: Utilized Cesium's scene picking mechanism to instantly capture latitude, longitude, and elevation values upon user clicks, enabling precise localization of heritage details.

(d) Immersive Roaming: Implemented interactive camera controls allowing users to navigate predefined routes, facilitating remote inspection and cultural dissemination by providing immersive panoramic views of heritage sites (Li,2021).



(a) (b)

(c) (d)

Figure 7. GIS functions

These functions significantly enhance the platform's capabilities in analyzing and visualizing spatial information of architectural heritage.

Building on the above, an attribute information query function for individual components was further developed. By adding unique identifiers to each architectural component (such as wall bricks, bracket sets, door lintels, etc.) in the 3D model and associating them with database records, when users click on a specific component, the system obtains the component ID through Cesium's scene picking API, and real-time retrieves detailed attribute information stored in the MySQL database—including material, geometric dimensions, repair records, etc.—which is displayed in an interactive panel (Figure 8). This function enables full-scale information management from the macro urban pattern to micro architectural components, providing digital tool support for the fine-grained protection and preventive maintenance of architectural heritage, and significantly enhancing the platform's capabilities in analyzing and displaying spatial information of architectural heritage.

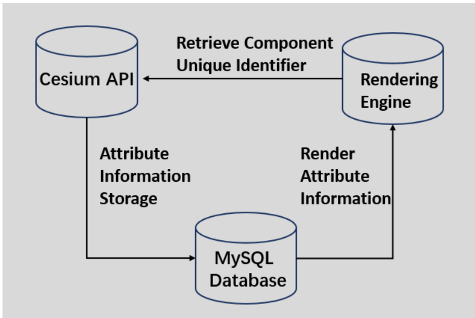



Figure 8. Attribute information display process

### 3.3 Organization of Associated Resource Files

Architectural heritage embodies historical, cultural, and technical values, and its preservation relies on the collaborative utilization of multi-type associated resources. Video materials record the restoration processes and cultural heritage, vividly showcasing historical features (Chen,2023); PDF documents contain academic research results and conservation plans, providing theoretical support for management teams; panoramic images offer immersive visualizations of heritage environments; CAD drawings precisely represent architectural structural details, supplying reference data for future conservation. Facing such diverse data formats, scientific file organization is crucial to enhancing preservation efficiency and quality. By establishing a unified storage and indexing system for structured management of heterogeneous resources, we can avoid data chaos and redundancy while enabling rapid retrieval and precise invocation, significantly improving research and management efficiency.

A standardized file organization system holds multiple significances for architectural heritage conservation (Figure 9): Technically, it breaks down data barriers, tightly linking 3D models with associated resources to provide comprehensive data support for heritage condition assessment, defect analysis, and restoration simulation (Thorkelson, 2007). Managerially, structured data facilitates the establishment of full-life cycle archives, assisting management departments in formulating scientific decisions. Culturally, the orderly integration of diverse resources enables richer dissemination of heritage values to the public, enhancing cultural identity.

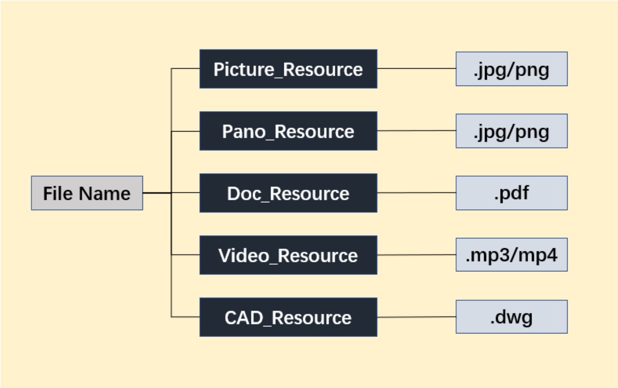



Figure 9. File organization methods

## 4. Experiments Process

### 4.1 Introduction to the Demonstration Building (Xingcheng Ancient City)

Xingcheng Ancient City (Figure 10), formerly known as "Ningyuan City", was first built in the 3rd year of Xuande in the Ming Dynasty (1428). As one of the four best-preserved ancient cities of the Ming Dynasty in China, it carries profound historical and cultural values. Located in the core area of the old city of Xingcheng City, Huludao City, Liaoning Province, its unique geographical location integrates cultural and natural landscapes: adjacent to Shou Mountain in the east, bordered by Jing-Shen Railway and Jing-Shen Expressway in the northwest, and surrounded by the Xingcheng River and East Xingcheng River, which flow through the city and into the sea, forming a natural historical and cultural barrier.

As a typical representative of the garrison cities in the Ming Dynasty, Xingcheng Ancient City features a rigorous and regular overall layout. The city wall stretches 821 meters from north to south, 816 meters from east to west, with a perimeter of 3,247 meters and an area of 700,520 square meters. The architectural patterns of the city walls, gates, and streets are well-preserved, completely demonstrating the military defense system and urban planning concepts of the Ming Dynasty, providing a rich and representative sample for the digital conservation and research of architectural heritage. This study uses Xingcheng Ancient City as test data for the architectural heritage visualization platform, aiming to comprehensively present the spatial form, historical details, and environmental characteristics of the ancient city through 3D modeling, GIS analysis, and multi-source data integration, and verify the practicality and efficiency of the platform in the digital conservation and display of ancient architectural heritage.

Figure 10. Xingcheng Ancient City

### 4.2 Experimental Environment and Testing Platform

This study conducts experiments and tests based on a stable hardware and software environment. In terms of software, Cesium 1.85.0 is adopted as the core 3D visualization framework, Vue 2.5.2 is used to build the front-end interactive interface, MySQL 5.7 manages multi-source data, and Visual Studio Code serves as the development tool. Hardware-wise, the testing platform is configured with Windows 10 system, equipped with an Intel Core i7-6700 processor and an NVIDIA GeForce RTX 3050 graphics card, ensuring efficient 3D rendering and GIS computation. Meanwhile, Google Chrome browser is used as the display terminal to guarantee platform compatibility and performance optimization.

### 4.3 Architectural Heritage Data Loading Test

Figure 11 shows the complete inclined model loaded into the architectural heritage visualization platform.

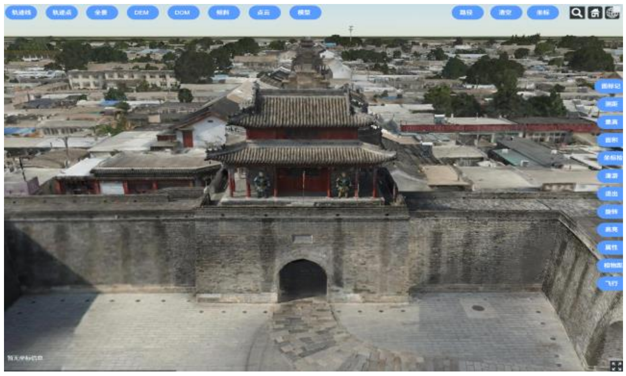
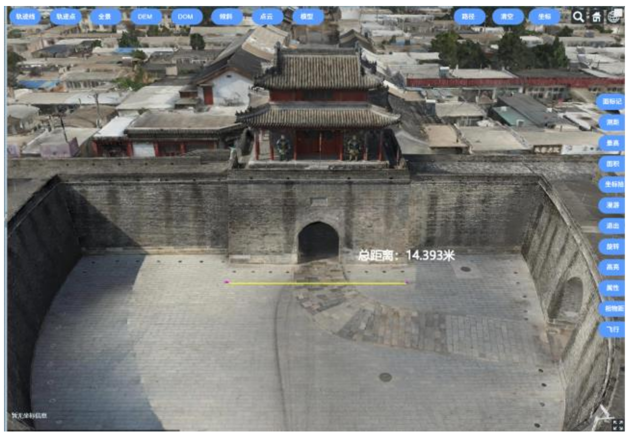
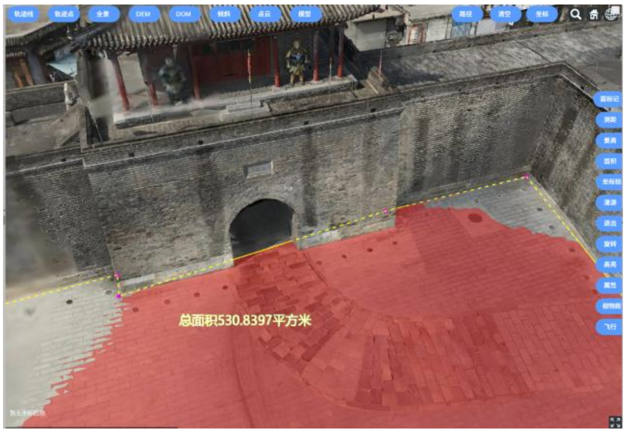


Figure 11. Overall model loading

Figure 12 shows the application and implementation of the distance measurement function and area measurement function.




(a)




(b)

Figure 12. Measurement results and display

Figure 13 shows the function of surface marking. For important building entities, a certain surface is marked as a key protection object.

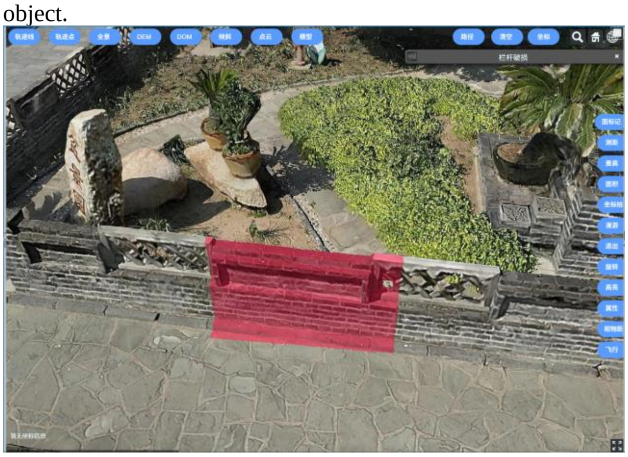
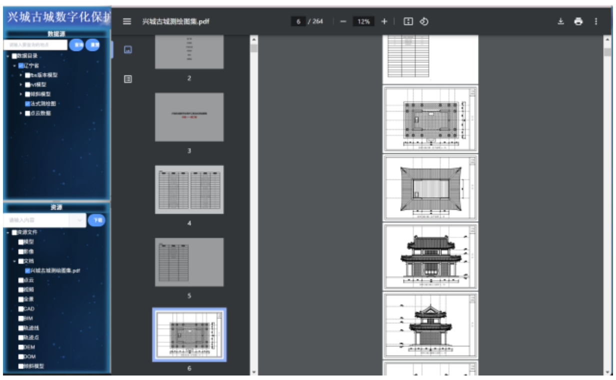


Figure 13. Highlighting the marked surface

Figure 14 shows the display of related resource files in the system.



(a) CAD resources

(b) Video resources

(c) Panoramic image resources

Figure 14. Resource files

## 5. Conclusion and Discussion

This study constructs a visualization platform for architectural heritage, which realizes dynamic display and interactive preview of 3D models, and integrates basic GIS analysis functions, supporting spatial attribute query, distance and area measurement, and other operations. For associated resources of architectural heritage, the platform adopts a standardized file organization framework to deeply associate fragmented data such as CAD drawings, panoramic images, and video materials with 3D models, forming a systematic digital asset system. This provides efficient heritage management tools for administrators and immersive cultural experiences for visitors.

Although the platform has demonstrated significant application value, the current research still has technical bottlenecks. When processing large-scale scene models, the system's loading performance significantly declines, and insufficient frame rates restrict the smoothness of visualization. Facing ultra-large 3D models, browser memory resources are easily exhausted, causing crashes. Additionally, the application of BIM models is constrained by strict splitting requirements, which necessitate disassembling complex structures into independent components, limiting the rapid deployment of refined models.

Future research will focus on core technological breakthroughs: developing efficient model lightweight algorithms to optimize the compression and transmission efficiency of massive data, and improving the system's rendering performance in complex scenarios; exploring automatic semantic information segmentation technology for BIM models to achieve intelligent disassembly and recombination of models, reducing the threshold for data preprocessing. Meanwhile, the compatibility and stability of the platform will be continuously improved to provide more solid technical support for the digital protection and active utilization of architectural heritage.

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