A Study on the Digital Reconstruction of the Foundation Platform of the Diji Altar and its Application in Restoration Practice

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Abstract

Digital restoration of ancient architecture is a key issue in the preservation and utilization of historical buildings. Traditional research has mainly focused on above-ground structures. In Chinese ancient architecture, scholars have emphasized timber-frame materials and craftsmanship. However, studies on the masonry and stonework of foundations remain limited. This gap represents the main focus of this study. Located in the core section of Beijing’s Central Axis, the Diji Altar is an important historical landmark. It is also a significant surviving example of ancient Chinese imperial ritual architecture. Existing studies have examined certain aspects of the Diji Altar. These include its ritual status and craftsmanship, as recorded in historical texts. Nevertheless, notable research gaps persist. The altar structure has sustained damage. Moreover, historical records lack sufficient documentation on its structural system, the form of its foundation platform, and corresponding stylistic evidence. As a result, systematic research on restoration techniques remains scarce. Such studies must rely on inferences based on architectural codes. Addressing this critical gap holds great significance. It contributes to understanding the technological achievements and ritual concepts of official architecture during the Ming and Qing dynasties. It also provides guidance for the restoration and preservation of ancient architecture.

1. Introduction

1.1 Historical Background

The Beijing Central Axis features a grand scale, a balanced and symmetrical planning pattern, and an orderly urban landscape. It is a combination of architecture and heritage sites that govern the planning structure of the entire old city. The Diji Altar is located in the core section of the Beijing Central Axis. It sits at the southern end of the Xiannong Altar complex. It faces the Temple of Heaven to the east and west. Together, they form an important ritual space in the southern section of the Central Axis.

The Diji Altar was first built in 1530, the ninth year of the Jiajing reign of the Ming Dynasty. It was a product of the national ritual reforms of the Ming Dynasty. Emperor Jiajing followed the ancient text Rites of Zhou to restore classical rituals. He implemented the separation of sacrifices to Heaven and Earth. He also ordered the construction of specialized ritual altars in the four directions of the capital. As the core unit of the southern part of the Xiannong Altar, the Diji Altar was dedicated to the mountains and rivers of the realm. These included the Five Sacred Mountains, the Five Fortified Mountains, the Four Seas, and the Four Great Rivers. Stone shrines were used to symbolize these natural features. The Diji Altar is a rare physical relic of mountain and river worship during the Ming and Qing dynasties (Hou 1988). First, it serves as a material embodiment of imperial political ideology. Through sacrificial rituals, it reinforced national unity and territorial identity. Second, its stonework, platform structure, and drainage system represent the highest craftsmanship of official masonry during the Ming Dynasty. They provide key samples for the study of ancient architectural technology. Third, as an important part of the ritual architecture complex along the Beijing Central Axis, the Diji Altar holds irreplaceable academic value. It helps reconstruct ancient ritual spaces and interpret the cultural significance of the Central Axis.

1.2 General Introduction

This study aims to address the gaps in the form and restoration techniques of the Beijing Diji Altar. These gaps are caused by structural damage and insufficient historical records. The research relies on inferences based on architectural codes. A multidisciplinary approach is adopted. The study systematically clarifies the historical form, construction methods, and material craftsmanship of the altar platform. Based on a condition assessment, it provides a rigorous academic foundation and technical support for scientific restoration and preservation. It also helps guide the structural reconstruction of the platform. The ultimate goal is to establish a complete workflow. This workflow spans historical research to technical application. It can serve as a reference for the restoration and preservation of similar ancient architectural platforms.

To achieve this goal, the study combines three methods: on-site surveying, comparison with historical texts, and 3D digital reconstruction. Fine-grained on-site surveys provide accurate primary data. Historical texts clarify official construction practices and codes. 3D digital reconstruction visualizes the structural logic of the platform. By integrating physical data with historical records, the study comprehensively reconstructs the original appearance of the platform. It also analyzes its construction features and restoration needs.

As an important altar in the royal sacrificial system of the Ming and Qing dynasties, most of the main structures of the Diji Altar have disappeared over time. However, the altar platform — the core element of the sacrificial space — has survived in a relatively complete state. Its overall form remains intact. It is a key physical relic for studying the construction system and ritual spaces of Ming and Qing official architecture. The existing altar platform exhibits typical features of Ming and Qing official architecture. It adopts a traditional structure of rammed earth core with brick and stone cladding. The proportions are well-balanced, and the side walls show clear inward inclination. These features reflect a solemn and stable official style (Wang 2009;Zheng 2016). Nevertheless, after centuries of weathering and human impact, the platform faces serious deterioration. Issues include brick and stone efflorescence, missing components, surface wear, minor localized settlement or deformation, and historical repairs that differ from original practices. These conditions not only threaten the long-term preservation of the site but also create challenges for accurately interpreting its historical form. Therefore, research on restoration techniques for the Diji Altar is of great importance.

2. Basic Techniques and Methods

The main technical methods include on-site surveying and field investigation, historical document verification, and 3D digital reconstruction and validation.

2.1 On-site Surveying and Field Investigation

Field investigation is a key step in obtaining primary data for this study. Through on-site surveying, photography, and condition assessment, comprehensive geometric and damage data of the current platform are collected. Modern surveying techniques, such as 3D scanning, are used to ensure accuracy and completeness. Detailed measurements are taken particularly for key components such as steps and sloping stones. A large amount of survey drawings and data are accumulated, and photographic records are collected. These serve as sources of basic architectural data and 2D images. The research team conducted systematic documentation of the Diji Altar platform. The main tasks are as follows:

First, Surveying Work. A combination of total station and manual measurement was used to conduct a comprehensive survey of the platform. The survey focused on overall dimensions, the proportion of inward inclination, and the precise height of each layer of masonry. Through detailed measurement, the platform’s inclination ratio was determined.

Second, Component Data Collection. With the widespread use of digital technology, photographing ancient architecture to record 2D images has become an important source of primary data. Various stone and brick components of the platform were measured and categorized. Photographs of key stone components were taken, and their dimensions were recorded. A detailed component database was established.

Third, Structural Joint Documentation. Attention was given to the connection methods between stone and brick, as well as between brick and earth. These included the layout of the drainage system. Such details were documented through photography and detailed survey drawings (Figure 1). Special attention was paid to the connection joints between steps and sloping stones. Traditional mortise-and-tenon stone connections were identified.

Fourth, Condition Assessment. Various types of deterioration were recorded in detail. These included weathering, cracks, missing components, and biological damage. The extent and location of each issue were documented. This provided a basis for condition assessment and future restoration priorities.

Figure 1. On-site photos.

2.2 Historical Document Verification

This study systematically reviews ancient texts and construction codes to clarify the historical form, construction methods, and hierarchical system of the Diji Altar platform. A theoretical basis is established through this process. Key texts are examined in detail. These include the Collected Statutes of the Ming Dynasty, Collected Statutes of the Qing Dynasty, Construction Methods and Regulations, and Masonry Methods of Ancient Chinese Architecture. Through these sources, the construction techniques and dimensional rules of the platform are thoroughly investigated (Liang 2006;Liu 1993). Historical records are consulted to understand the form, materials, and dimensions of the Diji Altar. On-site images, measurement data, and component types are then compared with textual records. Cross-referencing is carried out to validate and supplement the information. According to historical texts, the platform of the Diji Altar follows the construction standards of high-ranking altars and temples. However, its ritual status is slightly lower than that of the Temple of Heaven and the Circular Mound Altar. As a result, its materials and carvings tend to be simpler.

Through cross-comparison between physical data and documented regulations, the study validates, supplements, and refines the available information. The main components, forms, and dimensions of the platform, brick and stone elements, and steps are clearly identified. A reliable database of design dimensions and construction methods is established. Special attention is given to the dimensions of individual step components. These are analyzed in detail to ensure consistency with historical codes. This approach serves two purposes. It verifies the accuracy of the measurement data. It also allows for model refinement based on physical evidence. In this way, the reconstruction research is grounded in reliable sources.(Figure 2)

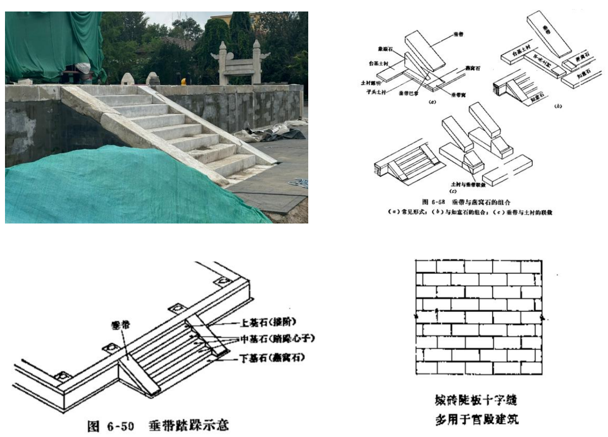

Figure 2. Comparison Between Measurement and Documents.

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2.3 3D Digital Reconstruction and Validation

Based on the integrated data and photographs, parametric and component-based modeling is carried out in SketchUp. The model is iteratively refined through continuous comparison with physical remains and historical records. Each component is classified, labeled, and textured. This process creates a digital twin that carries all research information.

3. 3D Digitalization of the Diji Altar

To systematically document the existing state of the Diji Altar platform and scientifically restore its historical form, this study introduces digital technologies and establishes a complete workflow from on-site investigation to model reconstruction.

First, the research is based on refined on-site surveying and condition assessment. A detailed data acquisition plan is developed to comprehensively record the geometric dimensions, structural relationships, and damage characteristics of the platform. On this basis, texture photographs and color information of the components are uniformly calibrated and processed. This ensures color accuracy and texture mapping precision. A comprehensive database is then established, integrating measured data with historical records. Through quantitative comparison between on-site measurement data and historical texts such as the Collected Statutes of the Ming Dynasty and Construction Methods and Regulations, the study objectively assesses the dimensional differences and formal evolution between the existing remains and their historical form. Finally, by integrating the results of condition assessment with findings from historical research, a 3D model of the Diji Altar platform is constructed. This model faithfully reflects the current state of the remains while remaining consistent with historical construction logic.

This process not only provides precise data support for the conservation and restoration of the Diji Altar, but also demonstrates the normative role of multi-source data integration and digital technology in architectural heritage research. It further highlights the importance of cross-disciplinary coordination and team collaboration in ensuring research quality.

3.1 Management Planning

To ensure the scientific rigor and standardization of the digital reconstruction of the Diji Altar platform, this study developed a comprehensive production management plan. Project management principles were applied throughout all stages, including data acquisition, processing, and modeling.

3.1.1 Preliminary Planning and Standard Development: Before the field investigation began, the research objectives and technical approach were clearly defined. A detailed data acquisition standard for the Diji Altar platform was established. This standard unified the naming conventions for components. An example is "Apron Stone-East-01." It also specified photography protocols, including angle, lighting, and color calibration using color checkers. A uniform format for recording dimensions was established. These measures ensured the systematic consistency and comparability of multi-source data from the outset. At the same time, a team communication mechanism was put in place. The roles and collaboration points among the surveying, historical research, and modeling groups were clearly defined.

3.1.2 Collaborative Acquisition: During the on-site surveying phase, a synchronized workflow of surveying, photographing, and recording was implemented. While 3D scanners were used to capture precise geometric data, each key component was individually numbered and photographed to document its surface condition. Data were organized on-site to verify component numbers against point cloud drawings. This helped prevent errors or mismatched information. Special structural features or damage phenomena were promptly annotated in both the drawings and the database. This ensured the completeness of the original records.

3.1.3 Data Integration and Cross-Validation： After the fieldwork was completed, the indoor data processing phase began. A comprehensive database was first established. Photographs, measured dimensions, damage descriptions, and documented standard dimensions from historical records for 62 key stone components were stored in a structured format. A dual verification process was then carried out, cross-referencing physical data with historical texts. Measured data from components such as apron stones and steps were compared with the dimensions recorded in the Construction Methods and Regulations. Components that conformed to the regulations were retained. Those with deviations were analyzed and documented. This provided a scientific basis for the subsequent modeling work.

3.1.4 Component-Based Modeling and Version Control： During the modeling process in SketchUp, a component-based approach was adopted. Each apron stone and step was created as an independent component and named accordingly. Assembly was carried out based on on-site positioning drawings. Strict version control was implemented throughout model iteration. At the completion of each stage — such as the main platform body or step details — backups were exported and modification records were documented. After the initial model was completed, multiple rounds of verification were conducted against on-site photographs and historical drawings. Texture information, mapping, color, and construction details were refined through this process.

3.1.5 Results Review and Archiving： The final model was reviewed internally by the team and by external experts. This ensured that it accurately reflected the current state of the site while remaining consistent with historical construction logic. All raw data, process files, and the final model were archived using standardized naming conventions. This created a traceable and reusable digital asset.

3.1.6 Role of Standardized Production Management： First, it ensured data accuracy. Standardized acquisition and cross-validation effectively prevented human error. This ensured that the model was built on a reliable and trustworthy foundation. Second, it improved research efficiency. Clear division of responsibilities and a well-defined data workflow reduced communication costs and repetitive work within the team. Third, it enhanced the reusability of outcomes. Component-based modeling and systematic archiving allowed the model to serve not only this restoration study but also to provide directly usable data modules for similar projects in the future.

3.2 Basic Data Acquisition

Basic data acquisition is an important part of this study. Its core objective is to comprehensively and accurately document the current condition of the Diji Altar platform through systematic technical methods. This provides reliable primary material for subsequent historical document comparison, morphological analysis, and 3D reconstruction. The acquisition work strictly followed the principle of "from overall to detailed, from geometry to texture."

3.2.1 On-Site Surveying and Data Acquisition：

Point cloud scanning was used to accurately determine the shape, size, and position of each stone component (Table 1). Each component was then numbered accordingly. On this basis, manual fine measurement was carried out for every stone component. For components such as apron stones, sloping stones, and steps, the length, width, and height were measured. For brick components such as platform facing bricks and paving bricks, the brick type and mortar joint width were recorded.

The main measurement objects included:

Classification and Statistics of Foundation Components (Diji Altar)

Unit: mm

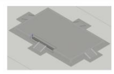
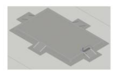
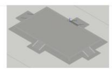
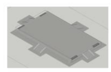
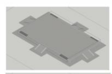
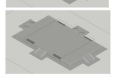
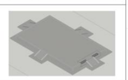
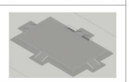
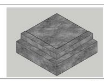
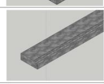
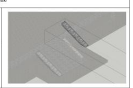
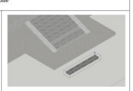
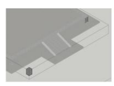
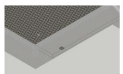
Number	Dimensions: Width	Length	Height	Component	Images of the Model
I. Apron Stone					
1-1	696	1: 1643 2: 1348	230	Apron Stone (at the four corners of the altar platform)	
1-2	696	8974	230	Apron Stone (Center of the West Side)	
1-3	696	11069	230	Apron Stone (Center of the South Side)	
1-4	696	3336	230	Apron Stone (Center of the East Side)	
1-5	696	4095	230	Apron Stone (Center of the North Side)	
1-6	696	3286	230	Apron Stones (East and West Sides of the Altar Platform)	
1-7	696	4089	230	Apron Stones (North and South Sides of the Altar Platform)	 
1-8	696	2847	230	Apron Stones (East Side of the Altar Platform)	
1-9	696	3493	230	Apron Stones (North Side of the Altar Platform)	
II. Base Stone					
2-1	891	300	100	Base Stone (at the Four Corners of the Altar Platform)	
2-2	896	300	100	Base Stone (of the Altar Platform)	
2-3	896	300	100	Base Stone (of the Steps)	
III. Sloping Stone					
3-1	450	3530	247	Sloping Stone (of the Platform)	
IV. Ruyi Stone					
4-1	370	4089	142	Ruyi Stone	
V. Step Tread Stone					
5-1	370	1387	142	Step Tread Stone	
VI. Corner Pillar					
6-1	690	690	1060	Corner Pillar	
VII. Square Paving Brick					
7-1	414	420	80	Square Paving Brick	

Table 1. Component Data Table.

All measurement data were recorded in tables on-site.

Each entry was matched with the corresponding component number. A major challenge during this process was the ambiguous determination of component boundaries. For example, when the end of an apron stone was weathered or missing, the measured length on-site was slightly shorter than its original length. The main strategy was to distinguish between original historical stone components and restored stone components in the model using color coding. Corresponding data were recorded accordingly.

3.2.2 Image Data Acquisition and Texture Recording:

A professional digital camera was used to photograph the platform. The focus included overall panoramic views, close-up shots of key components, and detailed images of structural joints. For important stone components, surface photographs with accurate color information were taken. This ensured color authenticity during later texture mapping.

3.3 Comparative Data and Discrepancy Assessment

Based on the established comprehensive database, this study conducted a systematic quantitative comparison between on-site measurement data and historical records. The aim was to objectively assess the morphological evolution and dimensional differences between the existing remains and their original historical form. This provided a scientific basis for refinement in the digital reconstruction process.

First, Construction of a Comprehensive Database. A component-level database was established for the Diji Altar platform. Each identifiable component served as a basic unit. Two major datasets were created: "stone components" and "brick components." The stone component database covered 62 key components. For each, the following were recorded: component number, on-site photographs, measured dimensions, and material characteristics.

Second, Quantitative Comparison Between Measured Data and Documented Standards. Three core component types were selected for focused comparison: apron stones, sloping stones, and steps. The measured data showed the following average dimensions:

· Apron stones: 312 cm × 69 cm × 23 cm
· Sloping stones: 353 cm × 45 cm × 24 cm
· Steps: 139 cm × 37 cm × 14 cm

These were compared with the Construction Methods and Regulations, which states: "Apron stones should be 2 to 3 chi in width and 5 to 8 cun in thickness." The analysis revealed that the apron stone width of 69 cm (approximately 2.07 chi) conformed to standard practice and closely matched the documentary record. The thickness of 23 cm (approximately 6.9 cun) also fell within the regulated range. The step height of 14 cm (approximately 4.2 cun) was slightly below the lower limit of the standard. This may be attributed to later stone trimming or weathering.

Third, Verification of Inclination Ratio and Structural Joints. Using point cloud data, the inclination ratio of the platform side walls was calculated as 1:0.02. This matched the Yingzao Fashi standard of "a reduction of 2 cun for every 10 chi in height," and was consistent with the measured inclination of the sloping stones. This confirmed that the overall dimensions of the platform strictly followed Ming and Qing official construction practices. At the connection between steps and sloping stones, a traditional mortise-and-tenon stone joint was identified. This matched the structural details documented in Masonry Methods of Ancient Chinese Architecture, confirming that this joint retained its original historical form.

Fourth, Discrepancy Analysis and Quantitative Assessment. The comparison showed that the main dimensions of the Diji Altar platform were largely consistent with documentary standards. However, two types of discrepancies were identified. Firstly, some apron stones showed reduced width due to weathering or later repairs. Secondly, traces of later restoration

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were found on certain apron stones. These discrepancies were quantitatively recorded and annotated in the database. They served as the basis for distinguishing between the existing condition model and the original appearance model during reconstruction.

3.4 3D Model Construction

After completing basic data acquisition, historical research, and quantitative comparative analysis, the study entered the core phase of 3D digital reconstruction. Parametric and component-based modeling was carried out in SketchUp. Each component of the platform, including various stone and brick elements, was created and placed individually. Special attention was given to the joining methods of different component types. Distinct colors and textures were assigned to different materials within the model. Historical original stone components identified during field investigation were separately labeled, clearly distinguishing original elements from later additions. Through continuous comparison with physical remains and historical records, the model was iteratively refined. It became a digital twin carrying all research information.

3.4.1 Data Integration and Modeling Preparation: Before modeling began, the component dimensions obtained from on-site surveying, point cloud data, images, and documented standard dimensions were systematically integrated.

3.4.2 Foundation Platform Modeling: First, a rough model of the platform was established based on the overall dimensions. The base stones, platform facing bricks, and apron stones were then created in sequence around the perimeter, forming a complete structure. During the modeling process, the height of each masonry layer was strictly controlled according to measured data. This ensured that the model fully matched the on-site survey drawings.(Figure 3)

3.4.3 Component-Level Detailed Modeling: A component-based modeling strategy was adopted. Each apron stone, sloping stone, step, and corner column was created as an independent component and named according to the on-site numbering system. For the steps, a seven-step model was precisely constructed based on the structural details documented in Masonry Methods of Ancient Chinese Architecture. All components were included, such as the mortise-and-tenon stone, the base stone, and the sloping stones. Special attention was given to the connection between the sloping stones and the steps. The brick facing of the platform was constructed using refined brick dimensions of 400 mm × 200 mm × 115 mm. A total of 11 courses were modeled.(Figure 4)

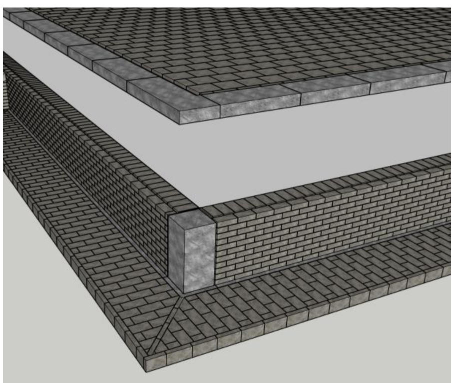

Figure 3. Detailed Modeling of Corner Columns and Bricks.

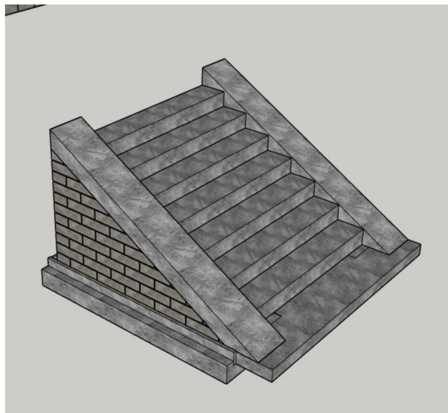

Figure 4. Detailed Modeling of Steps.

3.4.4 Materials and Labeling: In the model, distinguishing colors and textures were assigned to different materials. Special attention was given to original historical stone components identified on site, such as the yellow apron stones in the model. These were individually labeled to clearly distinguish original elements from later additions. This was crucial for restoration research.(Figure 5)

3.4.5 Model Validation and Iterative Optimization: After the initial modeling was completed, multiple rounds of comparison and verification were conducted between the model and on-site photographs, survey drawings, and point cloud data. The accuracy of component dimensions, spatial relationships, and structural joints was carefully examined.(Figure 6)

3.4.6 Data Quality Monitoring: To ensure the scientific rigor and accuracy of the 3D model, this study established a comprehensive data quality control mechanism throughout the entire workflow. Multi-level review procedures were implemented to guarantee the reliability and precision of the model outcomes.

(1). Internal cross-review by the team. After the preliminary model was completed, cross-verification was organized among team members from the surveying, historical research, and modeling groups. Key quality control checkpoints were established at each stage of the modeling process.

(2). Expert and external review. Specialists and scholars in the field of ancient architectural conservation were invited to conduct professional reviews of the model. Issues were identified and addressed, ensuring that the data received recognition from the professional community.

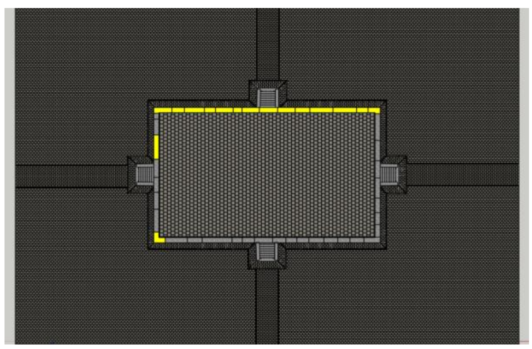

Figure 5. Final 3D Model.

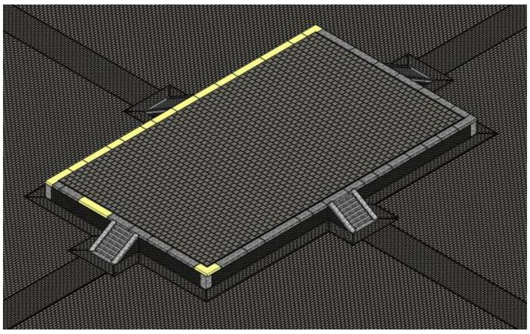

Figure 6. Axonometric View of the 3D Model.

4. Overall Research Workflow

The research workflow consisted of three main stages: field investigation, historical document analysis, and 3D digital modeling.

On-site investigation revealed several issues with the current condition of the platform. Some apron stones and corner columns showed weathering and cracking. Due to foundation settlement or external forces, localized settlement or deformation was also observed. A combination of point cloud scanning and manual measurement was used to conduct a comprehensive survey of the platform. The survey focused on the dimensions of individual stone components, overall platform dimensions, the proportion of inward inclination, and the precise height of each masonry layer. All stone and brick components of the platform were classified and documented. Photographs of 62 key stone components were taken, and their dimensions were recorded. A detailed component database was established.

Through careful study of historical texts, the overall form and construction logic of the Diji Altar platform during the Ming and Qing dynasties were clarified. The materials, dimensions, and construction methods of the brick and stone components were verified. On-site measurement data were cross-referenced and compared with documented standards. This ensured the accuracy and reliability of the data. Where discrepancies existed, the physical data were taken as the baseline, and a rational analysis was conducted with reference to the historical texts before being used in modeling.

Parametric and component-based modeling was carried out in SketchUp. Each component of the platform, including various stone and brick elements, was created and placed individually. Special attention was given to the joining methods of different component types. Distinct colors and textures were assigned to different materials within the model. Original historical stone components identified during field investigation were separately labeled, clearly distinguishing original elements from later additions. Through continuous comparison with physical remains and historical records, the model was iteratively refined. It became a digital twin carrying all research information.

The overall technical framework followed a closed-loop logic of "from physical evidence to historical texts, and from theory to digital verification." A high-precision 3D model was completed, ensuring the scientific rigor of the research process and the reliability of the outcomes. This provided visual technical support for restoration work.(Table 2)

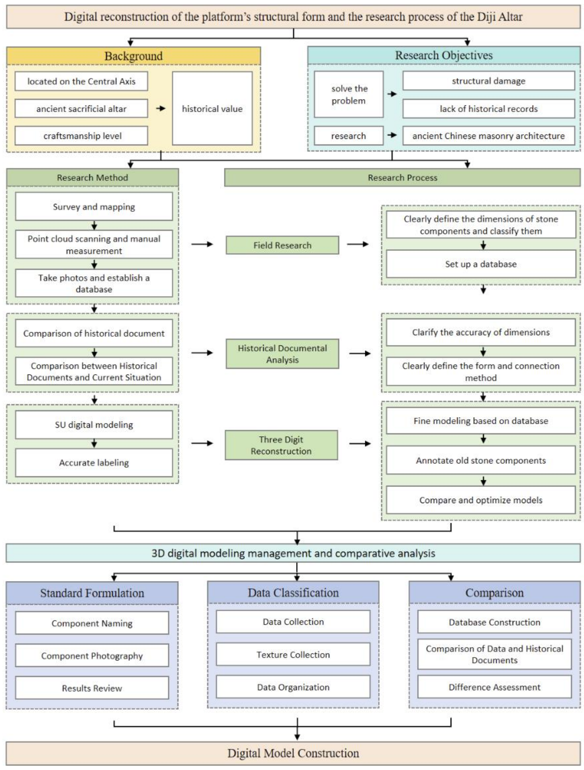

Table 2.Overall Research Workflow.

5. Conclusions

This study demonstrates that establishing a complete workflow—from data collection and historical document comparison to modeling and reconstruction—is an effective approach for the restoration of ancient architecture. Using the Diji Altar platform as a case study, this research fills a critical gap and confirms that constructing a component-level dataset integrating multi-modal data is an effective method for studying the form and restoration of historical architecture.

By systematically correlating and comparing field-acquired 3D point cloud data and image data with documented historical standards, this study reconstructed the original historical appearance of the Diji Altar platform. It provides a verifiable and reusable data paradigm for the study of official-style architectural platforms.

The component-based detailed modeling and intelligent labeling methods developed in this study ensure that each stone and brick component becomes an identifiable and analyzable independent information unit. These methods provide innovative tools for heritage conservation, research, and dissemination.

This research not only offers direct technical support for the scientific restoration of the Diji Altar but also provides a complete workflow and theoretical-practical model that can be referenced for the digital preservation and adaptive reuse of similar cultural heritage sites.

The broader application of this workflow promotes a more scientific, standardized, and systematic approach to the conservation and restoration of ancient architecture. It provides solid technical support and assurance for the preservation of China's outstanding traditional culture.

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