CREATING A 3D VILLAGE MODEL WITH MULTI-SOURCE DATA MODEL INTEGRATION: APPLICATION FOR THE PROTECTION OF ETHNIC ARCHITECTURAL HERITAGE

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1. Introduction

In the process of building and developing a modern village, the ethnic architectural heritage of traditional villages with research value and historical significance has been affected to varying degrees by irrational village planning as well as insufficient protection of the architectural heritage and inadequate protection policies. In addition, ethnic architectural heritage has suffered from different degrees of damage and destruction, due to natural factors such as rainfall [1-3], fires [4], and landslides [5], which has led to it being endangered or even destroyed [6]. Therefore, there is an urgent need to use digital technology to record the details of this heritage so as to ensure that there are references that can be used in the subsequent maintenance and protection of the ethnic architectural heritage, for the purpose of repairing the old architectural heritage [7-8]. There are many academic papers on digital preservation techniques for individual architectural heritage assets [9]. Techniques such as nap-of-the-object photogrammetry [10] and point cloud data [11] are used to collect data on the appearance of the built heritage, and to form a three-dimensional model, an approach that allows for the detailed recording of the external characteristics of the ethnic architectural heritage and its digital preservation [12]. However, the 3D modeling of a single building without considering the surrounding environment does not provide data support for traditional village planning and architectural heritage management [13].

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Recently, scholars [14-17] have begun to study the 3D modeling of architectural groups, which can document the architectural heritage in detail and carry out spatial analysis of the asset, including the situation of the surrounding environment, (e.g. road traffic, vegetation), so as to provide a basis for decision-making on the physical maintenance and protection of the architectural heritage. Modeling methods for city building groups include 3D real-scene from inclined photogrammetry, 3D modeling from point cloud data [17]. The steps in architectural group modeling include:

1. Building footprint generation, architectural data collection, architectural identification and classification, architectural model creation, and integration of an architectural 3D model [18-19]. The building script is created by aerial photography [20-21], google map [22], planning map.
2. The approach for building data acquisition includes photogrammetry, point cloud data measurement, architectural history data collection and literature review, in addition to generating the building group 3D model based on this building data information.
3. Finally, the building footprint is used as the base model by integrating the building group 3D model with the base model to form a 3D village model.

Due to the single type of urban buildings, and unified urban planning and construction, relevant research scholars have carried out research on the application of building group models in urban digital preservation. However, there are fewer studies on the application of architectural group models of ancient villages, especially traditional villages with ethnic architectural heritage, which have more diverse styles of ethnic architectural ontology and a more complex environment in the area around the structures. In the 3D village modeling process, the architectural heritage of the village needs to be finely modeled and integrated with the model footprint of the village. However, because the difference between the ethnic architectural and pseudo-classic architecture is small, it is difficult to identify the ethnic architectural and pseudo-classic architectural styles in the model footprint of the village. In addition, the roofs of some ethnic architectural heritage buildings are in disrepair, enclosure walls have collapsed, beams in the main body of the building are broken, and occasionally, even the whole architectural heritage structure has fallen into ruin, which increases the difficulty of modeling the building group. A building group model of the 3D traditional village needs to record the ethnic architectural heritage in detail, so the digital data for the ethnic building heritage can be conserved [23]. The ethnic architecture of traditional villages can truly reflect human social activities and the wisdom of construction in particular historical periods; for example, the intricate wood, stone and brick carvings of ethnic buildings reflect the superb skills of the craftsmen at that time. Therefore, it is necessary to record the current situation of ethnic buildings and restore collapsed ethnic buildings with the help of digital technology, so that historical researchers can carry out research on the history of ethnic architecture in traditional villages [23]. Existing building group modeling methods are difficult to adapt to the modeling of the ethnic building group of traditional villages, especially for the 3D modeling of the ruins of the architectural heritage that need to be restored and reconstructed. This paper proposes a modeling method for a 3D village that integrates multi-source models, which can cope with the requirements of modeling traditional village buildings with different levels of refinement. The method involves using a 3D real scene constructed by inclined photogrammetry as the footprint model for traditional villages, and identifying and classifying the buildings into ordinary buildings, ethnic architectural heritage, and architectural heritage ruins by examining the orthophotographs of the inclined photogrammetry model. The data for common buildings in traditional villages were collected using inclined photogrammetry. Lidar was used to collect the point cloud data for the ethnic architectural heritage and complete the 3D modeling; architectural heritage that was severely damaged or heritage ruins, were repaired and reconstructed using BIM technology based on the relevant historical information and the database of the architectural component models; different building models were integrated according to the location of the area in which they are located in the building footprint to generate the complete 3D model of the ethnic architectural heritage of the traditional villages in real life. The 3D model was integrated with many different data sources according to its location in the building footprint to generate a complete traditional village model.

2. Methodology

The focus of the traditional village 3D model is on the ethnic architectural heritage, which means that it needs to be modeled in a refined way. However, refined modeling will inevitably increase the internal storage space and modeling workload of the village 3D model. How to balance the relationship between the degree of refinement of the village model and the size of the internal storage is an urgent problem that needs to be solved. Digital modeling methods include inclined photogrammetric modeling, 3D modeling with point cloud data, and 3D modeling with Revit software. Their individual advantages and disadvantages are indicated below:

- Inclined photogrammetry has the advantage of fast data acquisition and reduced workload for automated modeling, but the constructed 3D model is not detailed enough and can only record the features of the building facade, which is suitable for 3D modeling of ordinary residential buildings in a traditional village.
- The Lidar instrument collects detailed structural point cloud data of a building at a high speed and is able to collect point cloud data of the facade and interior of a building, with the help of which a 3D model of the building can be generated quickly, so it needs a large memory storage. However, when used alone the memory of its 3D model may be too large because, in this case, the Lidar needs to be used to collect the point cloud data of only the most important architectural heritage, not of all the buildings.
- There are two approaches to restoration modeling of ethnic architectural heritage ruins: the first involves models of ethnic architectural heritage generated by Revit software which needs little internal storage. Drawings and textual materials of the building are required on which to base the 3D modeling process using Revit software. The second is to simply sketch the building outlines based on the available historical data, retrieve the parametric models from the database of ethnic building component models of traditional villages, adjust the size of the building component models according to the scale of the architectural heritage, and assemble the 3D model of the architectural heritage according to the connectivity relationship between the building component models.

In the paper, we classify the building types of traditional villages and carry out 3D modeling respectively. The building types are divided into common residential buildings, ethnic architectural heritage, and architectural heritage ruins. For the ethnic architectural heritage, we used Lidar to obtain the point cloud data for the architectural heritage and generate the refined model, while for the common residential buildings, we used inclined photogrammetry to generate the rough 3D model. For the architectural heritage ruins, the historical information was collected and assembled to form a BIM model based on the architectural heritage component model database. The modeling process for the specific traditional village 3D model is shown in Figure 1.

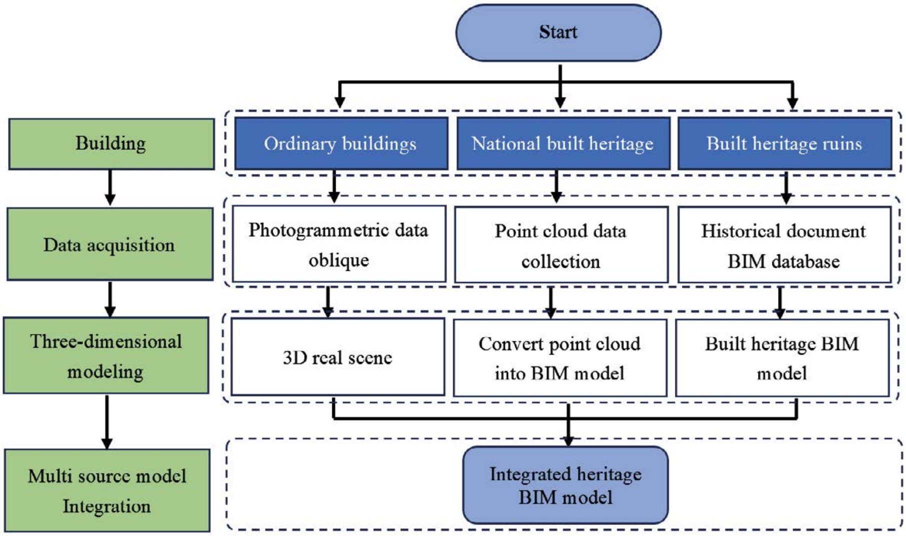

Figure 1. Modeling process for ethnic architecture in traditional villages.

The modeling steps for the ethnic architecture of traditional villages are shown below:

- Initially, orthophotographs of traditional villages were collected using UAV airborne high-definition cameras; in the orthophotographs, the traditional village was realistically reflected in terms of residential buildings, ethnic buildings, architectural sites, and the environment surrounding the ethnic buildings, including trees, roads, bushes, rivers, and so on.
- In the second step, in the orthophoto map of traditional villages, the deeplabv3+ algorithm was used to identify the buildings in the orthophoto map and classify them into different categories, such as residential buildings, ethnic architectural heritage, and ruins of architectural heritage.
- In the third step, an oblique photogrammetric survey data of the traditional village was carried out using a UAV on-board high-definition camera. The survey data was imported into the Bently software to generate a 3D real scene of the

traditional village, and this was used as the footprint model for the 3D model of the traditional village. The Lidar instrument was used to collect the point cloud data for the ethnic architectural heritage in all directions, including the façade and the interior of the building. For the collapsed ethnic architectural heritage, the architectural information was obtained by searching the drawings, historical image data and textual records of the architectural heritage. The 3D model modeling of the architectural heritage was carried out using Revit software. The 3D modeling of the ruins of the architectural heritage was completed by retrieving the model database of the ethnic architectural components of the traditional villages and assembling the ethnic architectural heritage.

- The fourth step was to use the tilted photographic model of the traditional village as a building footprint model, integrate the point-cloud model of the ethnic architectural heritage and the model of the reconstruction of the ethnic architectural heritage ruins, and form a traditional village 3D model with different levels of refinement for the ethnic architectural model.

3. Introduction of the traditional village of He-jie Town

A large number of traditional villages are concentrated in the He-zhou area, which is located in the north-eastern part of Guangxi, China. The ethnic architecture of traditional villages brings together ethnic architectural elements from many regions, forming an architectural style with strong local characteristics. The ethnic architecture of traditional villages in He-zhou has artistic ornamental value and historical research value. The paper takes Hexi Village of Hejie Town, a traditional Chinese village in He-zhou (the geographical location is shown in Figure 2), Guangxi Province.

Figure 2. Geographical location of Hejie Town in Guangxi province, China.

The building types of Hexi Village in Hejie Town include Ling-nan ethnic buildings from the Ming Dynasty and Qing Dynasty, brick-concrete structures of the Republic of China, and new buildings with ethnic architectural elements. The village contains more than ten ethnic buildings that are under key protection and are endangered. Some of the components of the ethnic buildings are seriously damaged and deformed, and their murals and textures are weathered to different degrees. Therefore, it is necessary to carry out 3D modeling and visualization of the ethnic buildings in traditional villages to provide a reference for the physical repair of their components.

4. Overview of the approach

The proposed 3D modeling method for traditional villages with multi-source data model fusion was successfully applied to traditional villages in Hejie Town, Hezhou, Guangxi. The method consists of four basic steps:

1. Creation of an ethnic architectural heritage distribution map of the traditional village.
2. Identification and classification of images of residential buildings, ethnic architectural heritage, and ruins of architectural heritage.
3. Development of three-dimensional models of the ethnic architecture.
4. Integration of the models from multiple data sources to achieve the creation of a model of the traditional village. This modeling approach ensures detailed documentation of ethnic architectural heritage while reducing the internal storage of the 3D model.

4.1. Collecting aerial views of the traditional village

A UAV on-board high-definition camera was used to fly over the traditional villages and take continuous photographs. The route of the drone flight was S-line, and in order to obtain a complete bird's-eye view, the overlap of the drone's heading was kept at 75% (±5%) during the flight, so as to obtain multiple top-view images of traditional villages with image overlapping. The top view images of traditional villages collected by the drone were stitched together using "Global map" software to form a high-resolution aerial view of ethnic architecture. The Aerial Views data acquisition schematic is shown in Figure 3A.

4.2. Identification and classification of architectural heritage from aerial views

The difficulty and workload of processing the architectural heritage of the aerial view using manual recognition and labelling is enormous. Therefore, it is necessary to use a DeeplabV3+ algorithm [24-25] of deep learning to replace human operation and achieve high efficiency image analysis and processing. The main steps in identifying and classifying the ethno-architectural heritage of traditional villages from an aerial view include: Extraction of color, texture and other feature information; sample labelling; deep learning algorithm training; identification results are shown in Figure 3B. The results of the aerial view recognition using deep learning algorithms include ethnic architectural heritage (in red), ethnic architectural heritage ruins (in blue) religious buildings (in green). Other buildings are considered as residential buildings.

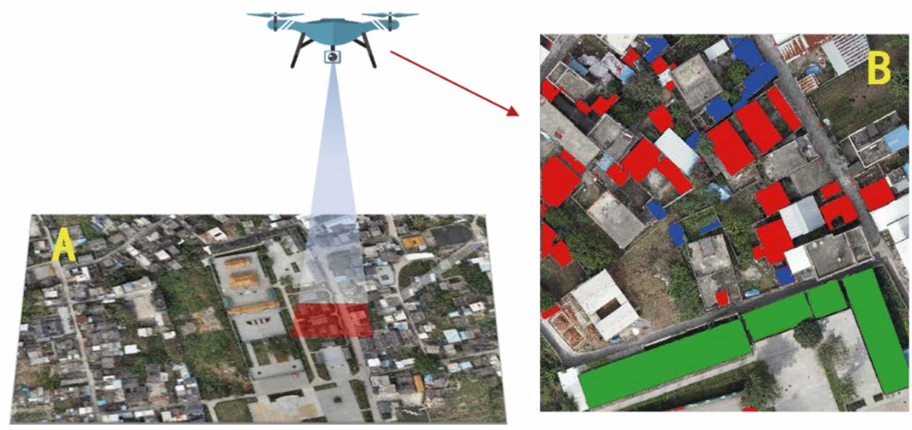

Figure 3. Traditional village aerial view data acquisition (A) and architectural heritage identification results (B).

4.3. Modeling methods for ethnic architectural heritage

4.3.1. Inclined photogrammetry modeling method

The object of the inclined photogrammetry is the traditional village ethnic architecture. There is an open environment around the buildings and no other shading between them, which is suitable for close range photogrammetry using the UAV onboard high-definition camera. The drone model is the DJI UAV M300 RTK with an onboard high-resolution five-lens tilt camera. The flight path of the drone is controlled by a human being or by a pre-programmed program. Close range photogrammetry [26] can be used for buildings that require a high degree of refinement. In order to ensure that clear image data of the component textures and frescoes of the structures are captured, the distance between the drone and the building wall is kept within 0.5 m during the close photogrammetric survey. During the nap-of-the-object photogrammetry process, we looked around the building and collected nap-of-the-object photogrammetric data for each façade of the ethnic building. The captured image data was imported into Bently's context capture to complete the 3D model (as shown in Figure 4).

4.3.2. Point cloud data modeling method

For the endangered ethnic architectural heritage of traditional villages, details of the ethnic architectural heritage need to be recorded in detail and preserved in the form of 3D models. The purpose of modelling using point cloud data is to serve as a reference for the physical restoration of the ethnic architectural heritage when the endangered ethnic architectural heritage is in a state of disrepair.

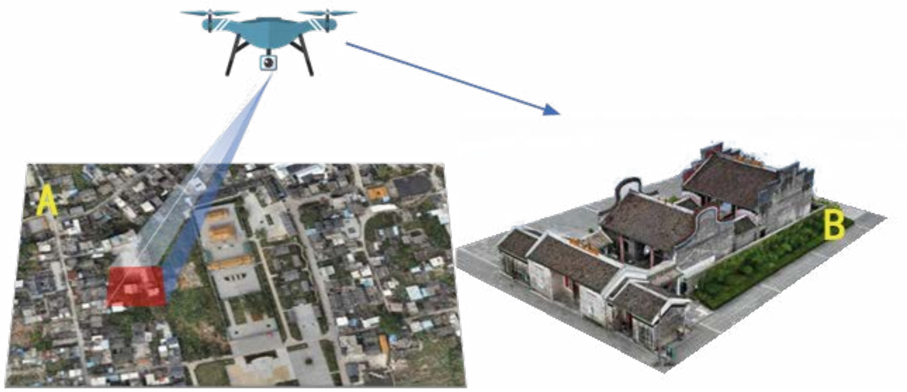

Figure 4. Image acquisition (A) and 3D model (B) of inclined photogrammetry.

The modelling process for the point cloud data model of the endangered ethnic buildings mainly includes point cloud data collector site deployment, point cloud data collector on-site data acquisition, point cloud data alignment and splicing, noise reduction and thinning, and point cloud data storage as 3D point cloud data in a LAS format [27]. Taking the brick-concrete monolithic ethnic buildings in traditional villages as an example, the point cloud data acquisition instrument used was the Leica Point Cloud Data Collector RTC360; the station deployment for point cloud data acquisition ensured that the acquired point cloud data had overlapping parts for the subsequent splicing of point transport data (as shown in Figure 5).

Figure 5. Data acquisition (A) and 3D Model of point cloud data (B).

4.3.3. Modeling method using Revit software

The difficulty of reconstructing architectural heritage models so they appear as the original is due to the lack of detailed drawings of the ethnic architectural heritage in ruins, as well as the lack of comprehensive and detailed historical textual and photographic information. The basic steps needed to reconstruct the architectural heritage in a state of ruin are:

- To determine the basic architectural information of the built heritage, such as building area, building height, building appearance, and to roughly outline the building by means of on-site surveys and field studies.
- To create a model database of architectural heritage components. Due to the lack of detailed architectural information on the ruins of the built heritage, which makes it difficult to restore them to their original condition, it is necessary to collect similar information on the building components and establish a database of models of the built heritage components.
- To retrieve and assemble components from the building component model database. Based on the basic information of the built heritage, the component model of the built heritage component model database is retrieved [28]. The assembly of the architectural heritage components is carried out according to the connection between the building components, so that a complete 3D model of the architectural heritage is formed.

The assembled building model is shown in Figure 6.

Figure 6. Parametric model assembly process (A) and multi-source model integration effects (B).

4.3.4. Multi-source 3D model integration

Taking the 3D real scene of traditional villages obtained using inclined photogrammetry as the building footprint model, and integrating the architectural heritage point cloud data model and the assembled architectural heritage model based on the architectural heritage identification results of the aerial views, a 3D village model with different degrees of fineness was created. The purpose of digitally recording specific heritage and creating a 3D village model is to utilize it in future plans for the protection of the ethnic architectural heritage of traditional villages. The 3D village model is shown in Figure 6.

5. Conclusions

The digital preservation of ethnic architectural heritage in traditional villages focuses on two main aspects: firstly, the detailed modeling of ethnic architectural heritage monolithic buildings; and secondly, as the ethnic architectural heritage in traditional villages does not exist independently, the 3D village model needs to record the condition of the environment around the architectural heritage. Therefore, it is necessary to construct a three-dimensional model of the traditional village, which can record the architectural heritage in detail. However, the more detailed the architectural heritage model, the larger the storage space required for the village model, which will also affect the operational effectiveness of the digital display of the village model. It is difficult to strike a balance between the fine-grained documentation of architectural heritage and the modelling of storage space that are contradictory in 3D village models. The paper successfully proposes a digital modeling method applicable to the ethnic architectural heritage of traditional villages and is based on 3D real scene models using inclined photogrammetry as the building footprint, integrating the point cloud data model and the building component model from the BIM database. Taking Hexi Village in He-jie Town of Guangxi as a case study, this paper has verified the effectiveness of the proposed method. Through the integration of multi-source data models, a traditional village 3D model was successfully constructed which contains a refined model of the ethnic architectural heritage. The village model provides an important digital basis for the conservation and restoration of ethnic architectural heritage. The research not only provides new ideas for the digital conservation of traditional villages but also lays the foundation for subsequent research on the construction of digital twin systems for ethnic architecture in traditional villages.

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Summary

Ethnic architectural heritage is mainly concentrated in ancient villages. The 3D models of ancient villages are of great significance in the protection of the ethnic architectural heritage in ancient villages. The aim of this study is to integrate multi-source data models to form a 3D model of ancient villages, which can provide detailed records of the ethnic architectural heritage and the surrounding environment and ensure that the memory space of the model is as small as possible. This will provide data support for the construction planning and physical protection of ethnic architectural heritage in ancient villages. Taking Hexi Village in He-jie Town of Guang-xi as a case study, different types of architectural models of ancient villages were modeled using technologies such as oblique photogrammetry, point cloud data, and BIM modeling. Through the fusion of multiple data models, a 3D model of the ancient village was successfully constructed, providing an important digital foundation for the protection and restoration of ethnic architectural heritage, opening up new ideas for the digital protection of traditional villages, and laying the foundation for subsequent research on digital twins of ethnic architectural heritage in ancient villages.

Riassunto

Il patrimonio architettonico etnico è concentrato principalmente in villaggi antichi e i modelli 3D di questi ultimi sono fondamentali per la loro tutela. L'obiettivo di questo studio è integrare modelli provenienti da più fonti per creare un modello 3D di un villaggio antico in grado di fornire dati dettagliati sul patrimonio architettonico etnico e sull'ambiente circostante in grado garantire che la dimensione del modello sia il più ridotta possibile. Ciò permette di realizzare un supporto dati per la pianificazione edilizia e la protezione fisica del patrimonio architettonico etnico nei villaggi antichi. Prendendo come caso di studio il villaggio di Hexi, nella città di He-jie, nel Guang-xi, sono stati modellati diversi tipi di modelli architettonici di villaggi antichi utilizzando tecnologie come la fotogrammetria obliqua, i dati di nuvole di punti e la modellazione BIM. Attraverso la fusione di più modelli di dati, è stato costruito con successo un modello 3D dell'antico villaggio, fornendo un'importante base digitale per la tutela e il restauro del patrimonio architettonico etnico, aprendo nuove idee per la tutela digitale dei villaggi tradizionali e gettando le basi per la successiva ricerca sui gemelli digitali del patrimonio architettonico etnico nei villaggi antichi.