Research of Ancient Architectures in Jin-Fen Area Based on GIS&BIM Technology

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Abstract. The number of well-preserved ancient buildings located in Shanxi Province, enjoying the absolute maximum proportion of ancient architectures in China, is about 18418, among which, 9053 buildings have the structural style of wood frame. The value of the application of BIM (Building Information Modeling) and GIS (Geographic Information System) is gradually probed and testified in the corresponding fields of ancient architecture’s spatial distribution information management, routine maintenance and special conservation & restoration, the evaluation and simulation of related disasters, such as earthquake. The research objects are ancient architectures in JIN-FEN area, which were first investigated by Sicheng LIANG and recorded in his work of “Chinese ancient architectures survey report”. The research objects, i.e. the ancient architectures in Jin-Fen area include those in Sicheng LIANG’s investigation, and further adjustments were made through authors’ on-site investigation and literature searching & collection. During this research process, the spatial distributing Geodatabase of research objects is established utilizing GIS. The BIM components library for ancient buildings is formed combining on-site investigation data and precedent classic works, such as “Yingzao Fashi”, a treatise on architectural methods in Song Dynasty, “Yongle Encyclopedia” and “Gongcheng Zuofa Zeli”, case collections of engineering practice, by the Ministry of Construction of Qing Dynasty. A building of Guangsheng temple in Hongtong county is selected as an example to elaborate the BIM model construction process based on the BIM components library for ancient buildings. Based on the foregoing work results of spatial distribution data, attribute data of features, 3D graphic information and parametric building information model, the information management system for ancient architectures in Jin-Fen Area, utilizing GIS&BIM technology, could be constructed to support the further research of seismic disaster analysis and seismic performance simulation.

Key word: Ancient architectures in Jin-Fen Area, BIM components library for ancient buildings, BIM model of Mahavira hall in Guangsheng temple
1. Introduction

The number of well-preserved ancient buildings located in Shanxi Province, enjoying the absolute maximum proportion of ancient architecture in China, is about 18418, among which, 9053 buildings have the structural style of wood frame. Four existing Tang Dynasty wooden structures and 75% wooden structures of the Five Dynasties are located in the Shanxi Province. The number of the National Important Historical Monuments under Special Preservation, being located in Shanxi, ranks first in China. In 1985, Sicheng LIANG has visited the research area of this paper to explore the Chinese ancient architectures and wrote “Record of the pre-investigation of the ancient buildings in the JIN-FEN area” [1] to record the characteristics of ancient architectures in JIN-FEN area. In this paper, the ancient buildings’ data in JIN-FEN area are collected as the sample group to research the protection of ancient building by using the BIM & GIS technology. The author built components models to form BIM components library for ancient buildings by using Revit software according to the “Yingzao Fashi” [2], an architectural practice book of Song dynasty, and tried to use the BIM library to build a whole ancient building. During this research process, the spatial distributing Geodatabase is established utilizing GIS to manage all the information collected for the ancient architectures in the research area. A building of Guangsheng temple in Hongtong County is then selected as an example to elaborate the BIM model construction process based on the BIM components library for ancient buildings.

2. Application of BIM technology in ancient building protection

BIM technology is widely used in the construction industry. Since it was invented for modern building modeling, it was primarily used in the planning, design and construction phases of buildings. Recently, BIM technology has begun to be used in the maintenance, renovation and management of existing buildings throughout their lifecycle. It is primarily used in the imitation and design of ancient buildings and combined with 3D scanning technology. The main process is using scanning equipment to three-dimensionally scan the whole building and the data will be uploaded to the cloud database, which are downloaded into the BIM software later to generate 3D building model. The advantage of this method is that it is possible to restore the appearance of the ancient building with high accuracy. Nevertheless, the accuracy of the model is greatly related to the performance of the scanner, and a 3D scanner costs a lot. BIM technology combined with 3D scanning technology for model construction is the method from the macro to the details, i.e. from the construction of the overall building model to the refined internal component models. In this paper, the author proposes a method of constructing ancient building models from micro to macro. Models of ancient wooden fabrications are built first, and then the whole ancient building model is assembled and adjusted.

In the latest research, Xiang LUO and Guohua JI introduced the application of Revit Architecture in parametric modeling of ancient buildings [3]. Weichao SUN introduced the detailed method of building ancient building information models with Revit Architecture [4]. Basing on the research of”Gongcheng Zuofa Zeli” written in Qing Dynasties, Weixin SUN studies the model parameterization of the ancient building’s components in Ming and Qing Dynasties [5]. Carlo Biagini et al. used the BIM technique to simulate the renovation and restoration of historical buildings, and the construction process is simulated, basing on a typical case study of the Nome di Maria church [6]. Maurice Murphy,
Eugene McGovern and Sara Pavia initially demonstrated the potential of HBIM in protecting historic buildings and the environment [7]. The ancient architectures in research area of Jin-Fen are partly built in the Song Dynasty, which has more referencing value for the study and protection of ancient buildings before the Qing Dynasty. Constructing BIM models of ancient building components is the main challenge, by referencing the rules and model illustrations of “Yingzao Fashi”.

In recent years, Historic Building Information Modelling was brought forward abroad. Historic building information modelling (HBIM) is proposed as a new system for modelling historic structures. The HBIM process uses a combination of a ground laser scanner and a digital camera to collect data remotely, and then uses a series of software programs to combine images and scanned data [7].

3. Ancient buildings of JIN-FEN area

The number of well-preserved ancient buildings located in Shanxi Province is more than 9000, enjoying the absolute maximum proportion of ancient architecture in China. Almost all types of buildings from Tang Dynasty to Qing Dynasty can be found here. Among them, 106 buildings were built before the Song Dynasty and 4 buildings were built in the Tang Dynasty. The number of ancient buildings, which were recorded in “Record of the pre-investigation of the ancient buildings in the JIN-FEN area” is 20. These buildings include a building of Song Dynasty, JIN ancestral temple, ten buildings of the Yuan Dynasty and four buildings of the Ming Dynasty. Therefore, it is a very meaningful work to follow the footprint of Sicheng LIANG to explore the current situation of the ancient buildings in JIN-FEN area, which is especially beneficial for the maintenance of existing ancient buildings. The Current situations of ancient buildings in JIN-FEN area are shown in Table 1.

| Name                           | Current situation       | The cause of the damage |
|--------------------------------|-------------------------|-------------------------|
| Tianlong temple                | Disappear               | Unknown                 |
| Chongsheng temple              | Disappear               | Unknown                 |
| Lingyan temple                 | Pagoda and caves preserved | War                    |
| Guoning temple                 | Disappear               | Unknown                 |
| Shengmu temple of Wenshui county | Disappear            | Military                |
| Wen temple of Wenshui country  | Disappear               | Unknown                 |
| Dongyue temple                 | Disappear               | Road widening           |
| Taiqing temple                 | Disappear               | Unknown                 |
| Wen temple of Huozhou county   | Disappear               | Unknown                 |
| Zhusheng temple                | Some preserved          | Occupied by flour factory |
| Xifuchang temple               | Disappear               | Unknown                 |
| Shengmu temple of Huozhou county | Disappear            | Unknown                 |
| County yamen of Huozhou county | Well preserved          |                         |
| Bridge and iron ox             | Disappear               | Flood                   |
| Nvwa temple                    | Disappear               | Unknown                 |
| Guangsheng temple              | Well preserved          |                         |
Unfortunately, Sicheng LIANG's visiting did not arouse local people's awareness of the protection of these buildings. Since the reform and opening up, only seven ancient buildings survive, i.e. Jinci temple (Song Dynasty), Guangsheng Higher and Lower temples (Yuan Dynasty), Mingying temple, Yamen of Huozhou County, Zhushen temple of Huozhou County and Lingyan temple (Ming Dynasty), and the rest are destroyed due to war or other reasons. Now, some existing architectures, such as Jinci temple, have become famous tourist attractions and received enough investigation for maintenance and protection from the government every year. Because of the raising awareness of the protection of ancient buildings, some of the ancient buildings were renovated and rebuilt by the local villagers. However, methods of refurbishment and reconstruction are very inappropriate, which make ancient buildings become cement constructions and lose historical value. Such kind of behavior causes irreparable loss to the valuable ancient architectures. The Protection of ancient buildings should be the protection of their cultural value and the maintenance of their original appearances.

![Spatial distribution map of ancient buildings in JIN-FEN area](image_url)

As shown in Figure 1, JIN-FEN area is actually around the Yudao river, which includes Wenshui county, Xiaoyi county, Huozhou city, Hongtong county and Taiyuan city. Most of the ancient architectures are located in villages, where the protection measure is weak and only simple and original means are adopted to keep them from collapsing. It is very urgent to take steps to protect these disappearing ancient architectures.

4. BIM models of ancient buildings

Chinese ancient buildings are mainly composed of large wood components, and can be separated into scattered components. The sizes and construction sequence of these wooden components must obey detailed rules. Hence models of ancient wooden components should be built first, and then the whole ancient building model could be built according to the structure system of the building. The BIM components library for ancient buildings is an important basis for the construction of the whole
building model, which should contain abundant BIM models of ancient building components. In the construction process of the BIM components library for ancient buildings, “Yingzao Fashi”, the official code for constructional engineering in Song Dynasty, is referenced, which is the most complete architectural technology book in Chinese history. It is an indispensable reference book for the study of the architectures built in and after Song Dynasty. For better understanding of this ancient book, “Notes of Yingzao Fashi”, which is written by Sicheng LIANG, is referenced too. Every BIM model of ancient building components is constructed by Revit software.

4.1 Revit models of ancient building components

Chinese ancient buildings abide by the strict hierarchy. The scales of residential buildings (area and high) are based on the owner’s official position, and the sizes for the wood components (beam, column, etc.) are correspondingly different. The authors use Revit software to build the components’ models, in addition to the basic door, window and column, the other particular models are shown in table 2.

### Table 2. Models of components.

| Name               | Type | Diagram |
|--------------------|------|---------|
| NI-DAO Gong Gong   | Gong | ![Image](image1.png) |
| MAN Gong           | Gong | ![Image](image2.png) |
| LING Gong          | Gong | ![Image](image3.png) |
| SAN Dou            | Dou  | ![Image](image4.png) |
| QIXIN Dou          | Dou  | ![Image](image5.png) |
| LU Dou             | Dou  | ![Image](image6.png) |
| JIAOHU Dou         | Dou  | ![Image](image7.png) |

The construction of the BIM components library for ancient buildings is mainly through the method of constructing BIM families in Revit software, which can be controlled by the set family parameters. Each BIM family, representing a particular component of ancient buildings, shares the same shape and feature, and the specified size for different buildings can be adjusted for the corresponding building. The Completion of the library of BIM components will greatly speed up the establishment of ancient models of buildings.

4.2 BIM model of Mahavira hall in Guangsheng temple

Guangsheng temple is located in Hongtong country, and buildings of the temple were mainly built in Yuan Dynasty (year 1309). This temple is a National Important Historical Monuments under Special Preservation. Mahavira hall of Guangsheng temple, which was also built in the Yuan Dynasty, is taken as an example to elaborate the construction process of BIM model. The main structure contains seven halls, and the doors are set in the central three halls. High mullioned windows are set by the right and left side of the doors. The roof style uses suspended hill. The construction of Dougong is five sets,
heavy Gong, and only used in column cap, without Dougong sets between columns. The size of Dougong is bigger than usual, and the comprehensive design is relatively concise. The distribution of columns adopted the method of moving and minus columns, which is popular in Song Dynasty, to reduce the number of inner columns and increase inner space.

The construction of the BIM model of Mahavira hall of Guangsheng temple mainly contains three steps. The ultimate BIM model of Mahavira hall of Guangsheng temple is shown in Figure 3, comparing with the photo of the hall.

4.2.1. The overall structure of Mahavira hall.
According to the “Chinese ancient architectures survey report”, the basic information and architectural plans of the building are obtained, it is 25 meters long and 14.6 meters wide with a total area of 365 square meters. It is clearly shown in this picture that the eave columns and inner columns were not centered, which reveals the method of moving and minus columns.

![Figure 2. Architectural plan of Mahavira hall.](image)

4.2.2. Analysis of the components type.
The types of ancient architecture components, being used in Mahavira hall and construction mode, are summarized by on-site investigation and literature searching & collection.

4.2.3. Construction of the whole building model.
The Revit models needed for Mahavira hall are selected from the library of BIM components. For the Dougong area, a complete Dougong is firstly constructed to form a new family file by combining Dou, Gong and other components. Then the columns, beams, Dougongs are placed according to the architectural plan. Finally, the roof is built by the built-in models in Revit.
4.3 Conclusion of the BIM modeling process of Mahavira hall

The method of building the entire model based on models of components, according to “Yingzao Fashi”, is proved to be feasible and has satisfactory accuracy, and the BIM components library for ancient buildings can be reused for the building of new ancient architectures models in the future. Through a typical case study of a building in Guangsheng temple, some suggestions on using BIM software for the construction of ancient architectures models are put forward.

1. About the heights of the ancient architectural columns. “Yingzao Fashi” can be used as a reference for us, but the actual size of the component should come from on-site investigation. The height of columns of the Mahavira Hall, according to “Yingzao Fashi”, should be ten meters. However, it more meets the standard high of eight-Yuanjian hall, about 4.83 meters.

2. The ancient walls are thick. For example, the wall of Mahavira hall is 2.4 meters in thickness. The built-in model method in Revit software is used to establish inclined walls and their surface.
coating.

3. The problems about the open and overlapping order of Dougong should be noticed. Constructing complete Dougong BIM families, using the existing components models form the library, could facilitate the following work.

4. Roof is the main component of an ancient building, which has many decorative objects with Chinese characteristics. Hence it is better to use the built-in model method in the new file to build a roof, and then use the link to the original Revit file to combine two documents.

5. The whole model is usually made up of various components, and the model accuracy should be set differently considering the character of these components. This point will be elaborated in the following section.

4.4 Accuracy of ancient building model

In order to make the BIM models of ancient buildings more credibility and have more historical value, certain accuracy standards should be obeyed to construct the BIM models. The accuracy for the main structure of the ancient buildings are differently defined, considering the features of components, and these components are classified to be Dougong, roof, joinery work (doors, windows, railings, etc.), carpentry work (columns, beams, purlins, etc.), and masonry structures for corresponding accuracy needs.

The accuracy of the model depends on the purpose of it. Referencing the analysis of surveying and mapping accuracy of relic building, Zhewen LUO, a specialist of ancient building, divided the purposes of surveying and mapping of relic buildings into three levels, i.e. forming “scientific records”, “fundamental drawing information for repairing design and construction” and “basic information for the research of Chinese architectural history and architectural theory” [8]. Therefore, the accuracy of the ancient building model can be divided into three levels. The first level is suitable for the model construction of the important ancient buildings, which requires the complete construction of Dougong and decorations on roof and carpentry work, and refined joinery work for the models. The second level is applicable to the establishment of scientific management archives of ancient buildings, which requires that the important decorations on roof, carpentry work, and joinery work should be constructed, and Dougongs should be constructed to satisfy the requirements. The third level is suitable for the analysis and survey of the ancient buildings, and the construction of the model is only required to express the information of size, quantity and materials.

5. Conclusion

The destruction and extinction of ancient buildings in JIN-FEN area in the past few decades represent the situation of the ancient architectures of China. Now it is critical to take steps to protect their original states and slow down the disappearing speed. GIS and BIM technology can be an effective tool for protecting, retrofitting, renovating and managing of existing ancient buildings. With the development of science and technology, the protection of ancient architecture should also develop with advance of the times.

Based on the foregoing work results of spatial distribution data, attribute data of features, 3D graphic information and parametric building information model, the information management system for ancient architectures in Jin-Fen Area, utilizing GIS&BIM technology, could be constructed, which is beneficial to the protection of cultural heritage, the management and preservation of ancient
building and also supports the further research of seismic disaster analysis and seismic performance simulation combining with the structural analysis software and seismic analysis software, such as PKPM, SAP2000 and Autodesk Robot Structural Analysis.

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