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# Research on Pathology Information Management of Educational Architectural Heritage Based on Digital Technology: The Case of James Jackson Gymnasium

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**Abstract:** Rapid advances in technology have led to an increasing demand for this type of information in the field of cultural heritage and architectural conservation. The article aims to use digital technology to obtain, record, store, and display accurate and intuitive information about architectural heritage for daily management and repair of that heritage. This article conducts a comprehensive and in-depth study of the pathology information from the James Jackson Gymnasium, a typical case of the modern educational architectural heritage of Wuhan. Research contents include obtaining point cloud data through 3D scanning, constructing Building Information Modeling (BIM) 3D models and pathological information models to visualize the affected parts, using the Monument Damage Diagnostic System (MDDS) to establish a pathological information map management system, using virtual simulation technology and digital repair technology to diagnose and repair the affected parts, and establishing a systematic architectural pathology information database to explore the causes of architectural pathology from a multidisciplinary perspective. The authors aim to gradually promote this method and build a systematic pathological information database of architectural heritage. This utilizes the sharing characteristics of information technology to transcend the barriers of time and space and provide important support for heritage protection and pathology management. The Architectural Pathology Information Management System is proposed as an innovative solution to promote the sustainable conservation of architectural heritage through digital technology.

**Keywords:** pathology information; digital technology; cultural heritage; sustainable conservation; BIM

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## 1. Introduction

Protecting historical buildings equates to the preservation and perpetuation of historical culture. The State Council of China promulgated the "14th Five-Year Plan for the Development of National Science and Technology for Cultural Relics Protection [1]", which insists that cultural relic protection "focus on prevention and control at the source, and comprehensively enhance cultural relics safety early warning and prevention and control capabilities". The Ministry of Housing and Urban-Rural Development of China promulgated the "Three-Year Action Plan for Surveying, Mapping and Archiving of Historic Buildings and Standardizing the Results of Surveying, Mapping and Archiving of Historic Buildings [2]", mandating all provinces in China to conduct surveys, mappings, and archival endeavors pertaining to historical structures. However, conventional architectural surveying and mapping hinge upon manual measurement, which is not only low in accuracy, time-consuming and labor-intensive, but also easily affected by factors such as surveyors and environmental conditions, which may lead to secondary damage to historical buildings. Furthermore, the preservation of requisite paper data for surveys presents challenges, compounded by various complexities that exacerbate the arduousness of historical building surveys. Therefore, the systematic management of historical building data through advanced information detection techniques holds paramount importance in safeguarding, preventing pathologies, and restoring historical edifices.

Educational architectural heritage serves as a testament to the evolution of educational culture and architectural practices. Its distinctive cultural characteristics occupy a significant position within architectural heritage. The protection of educational architectural heritage has received widespread attention from scholars. For instance: The United States promulgated the National Historic Preservation Act (1966), which listed educational buildings over 50 years old in the National Register for complete protection [3]. The United Kingdom has systematically protected a number of university campuses built in the Middle Ages, such as Oxford University and Cambridge University, in the Ancient Monuments Act [4]. China has also well preserved a number of educational architectural heritage properties. Among the eighth installment of China's national key cultural relic protection program, there are more than 70 educational architectural heritage properties [5]. However, China's current research on educational heritage focuses on protection and reuse, and the information-based surveying and mapping of educational heritage is in an independent and decentralized state. Particularly noteworthy is the dearth of research regarding early warning systems for cultural relic safety and measures for the prevention and control of pathologies.

Wuhan stands out as one of the foremost emblematic cities in modern China. Established as a treaty port with Western countries in 1858, it earned the moniker the "Chicago of the East" in the early 20th century [6]. It has a rich educational architectural heritage. From 1840 to 1949, Wuhan's modern educational architecture experienced a century of development, laying a solid foundation for today's education industry. Wuhan's modern educational architecture has introduced new educational models from Western countries and a combination of Chinese and Western architectural styles [7]. It mirrors the characteristics and historical features of the time and is also an important witness to the cultural exchanges between China and the West in modern times. It occupies a distinctive position in the history of modern education, architecture and social development in China. Therefore, this study selects Wuhan's modern educational architectural heritage as the research object to be typical and representative.

Building Information Modeling (BIM) technology was initially introduced in 1974 [8] and was subsequently implemented on a technical level by Autodesk in the early 21st century. BIM is based on three-dimensional digital technology and integrates various relevant information in construction projects into an engineering data model [9]. This model serves as the cornerstone for interdisciplinary collaboration and facilitates comprehensive lifecycle management of buildings, spanning from architectural design and construction to subsequent monitoring, operation, and maintenance.

Historical buildings are susceptible to natural or anthropogenic factors due to poor operation and maintenance. In order to protect this cultural heritage, it is necessary to preserve their information in digital form. Therefore, this article takes the James Jackson Gymnasium, a classic case of historical architecture, as the research object. It studies everything from data scanning, three-dimensional modeling to pathology information acquisition and cause analysis, and records the information to facilitate subsequent maintenance and inspection. The purpose is to promote the sustainable development of heritage protection and urban renewal through this work.

## 2. Literature Review

In recent years, the academic community has carried out various studies on the digitalization of historical architectural heritage protection. It can be summarized into the following aspects:

HBIM, laser scanning, etc. HBIM research focuses on the construction of historical building BIM models, BIM modeling influencing factors and integrated information platforms. For instance, Li et al. (2015) [10] analyzed the five main influencing factors of BIM technology application in historical buildings through various channels: software, talent, environment, concept and economy, and put forward improvement suggestions for these factors. Murphy et al. (2015) [11] combined BIM with 3D laser scanning and photogrammetry to explore the process and method of establishing HBIM models. Angulo-Fornos et al. (2020) [12] took the Renaissance facade wall of Seville Cathedral in Spain as the object to study HBIM generation and proposed a method for semi-automatic modeling of historical buildings. Shi et al. (2014) [13] took Beijing residential buildings as the research object and used point cloud scanning technology to obtain architectural space, material and other information to reversely establish historical building component families and models. Taking the main hall of Zhengzhou City God's Temple as an example, Yang et al. (2020) [14] refined the process of establishing a historical building component family based on laser scanning, manual measurement and high-definition photo information, achieving the concretization of complex geometric information and the visualization of historical information. Ma Junjie (2023) [15] studied the application of BIM in the repair of ancient bridges and the design information collection process and explored the parametric design of stone components and the application of BIM models in the layout of structural monitoring points. In the field of ancient building protection, Liu Qingyu (2016) [16] not only uses Rhino 5.0 for three-dimensional modeling but also uses professional software to conduct thermal analysis and structural analysis of protected objects. Through the combined use of BIM technology and professional software, the purpose of simulation experiments on cultural relic buildings was achieved. However, there exists a disconnect between the analysis conducted through professional software analysis and the application of cultural relic building information models. Integration of these aspects stands as a prospective avenue for the future advancement of BIM application in historical building protection.

BIM, VR technology, etc., use VR technology to virtually display BIM digital information. Currently, the virtual display of digital information regarding historical buildings constitutes a research focus within BIM concerning architectural heritage protection. For example, Stanga, C. et al. (2023) [17] have used technologies such as BIM and VR to build historical sites that can be explored virtually and to protect cultural heritage by providing opportunities for education and tourism. Ma, Y.-P. (2021) [18] integrates BIM data of historical buildings and extends those data into the virtual environment, allowing users to perform virtual reality and environmental interaction and then conduct restoration research. Ji et al. (2018) [19] used BIM, VR and video analysis technologies to develop a historical building restoration and virtual training system and established a digital historical building model containing three-dimensional models and attributes. The three-dimensional model is uploaded to the network platform, and users can browse it at high speed through the browser and perform functions such as virtual construction and disassembly, thereby gaining an in-depth understanding of the historical building structure and construction process. Baik et al. (2021) [20] used BIM information models combined with point cloud data to build a three-dimensional interactive environment, providing a virtual three-dimensional model with rich interactive forms for historical building management. Shang et al. (2021) [21] studied the use of HBIM by Sunxi Academy in Taichung City to visualize historical building data information. Li Ke (2016) [22] applied the design results of historical buildings to the BIM model to realize the integration, organization and management of discrete engineering data information and generated thematic drawings through views, schedules, models, etc. This makes the logic expressed clearer and the degree of visualization stronger. Based on the above applications of BIM in historical buildings, people mainly focus on BIM data collection, model construction, virtual restoration and building information integration, etc., and neglect research on the actual monitoring, management and preventive protection of historical building pathology.

Pathology information management of historical buildings. Today, research on pathology information management and preventive protection of historical buildings is still in the exploratory stage. Ferraz et al. (2016) [23] analyzed the literature related to building pathology detection technology and methods and concluded that there is currently no management system for quickly obtaining pathology information and that the importance of building a pathology information management system is emphasized. Acampa et al. (2020) [24] used the HBIM model to analyze the aging factors and maintenance management of columns in the Patio de Los Leones in Alhambra, Spain. Israeli scholars used three-dimensional laser scanning technology to collect data on the severely damaged walls of Jerusalem's historical buildings and drew flat, vertical, and cross-sectional views of the walls, which provided a data basis and repair plan for subsequent wall protection. Liu et al. (2013) [25] used three-dimensional laser scanning technology and close-range photogrammetry technology to collect data on the ancient city of Pingyao. The bulging and damage to the wall are being studied, and the crack-measuring instrument is installed on the wall to realize long-term observation of the cracks in the wall to understand the changes in the length and depth of the cracks. Sanchez et al. (2023) [26] used technologies such as infrared thermal imaging, 3D optical roughness and acoustic impedance gun measurement to identify early damage to building stones and limit the growth of the pathology by early detection of pathological processes and by taking protective measures. He et al. (2018) [27] used three-dimensional laser scanning to scan the damaged area of ancient city wall bricks and explored the number of bricks required for repair.

At present, the practitioners in industry, business and academics are gradually applying BIM, three-dimensional laser scanning, oblique photogrammetry and other technologies to the protection of historical buildings, which greatly reduces the work of field personnel, but are only at the early stage of data acquisition and model construction. A few scholars have conducted research on later architectural restoration simulations. However, the pertinent research content and methodologies are comparatively rudimentary. Especially in the current field of building pathology prevention, there is a lack of systematic research combined with BIM and other technologies. In view of this, this article takes the modern educational buildings in Wuhan as the research object and chooses the James Jackson Gymnasium, the most representative historical building among them, as an example. BIM technology and computer simulation technology are used to visually manage and monitor historical building pathology, and a blend of qualitative and quantitative research is used to establish a comprehensive, multi-level, and systematic building pathology information management database.

The main innovations of this article are as follows:

- Using three-dimensional scanning technology to acquire point cloud data with pathology information and visualize BIM pathology areas by building a BIM pathology information model; using qualitative and quantitative methods, constructing the pathology information database so that people can observe the pathology information and development trends of each building part in an all-round and multi-angle manner. This will allow practitioners to take preventive and control measures against building pathologies more efficiently and promote the sustainable protection of historical buildings.
- Establishing a BIM model for pathology map management based on the international MDDS (Monument Damage Diagnostic System) cultural relic damage diagnosis system. This provides guarantees for the management, protection and repair of historical buildings, ensures the safety, authenticity and integrity of historical buildings, and realizes the sustainability of historical building heritage information.
- Delving into the causes of building pathologies from a multidisciplinary perspective and proposing corresponding prevention and control measures. Ecotect building

energy consumption analysis software is used to interact with the BIM model to analyze building pathologies induced by the natural environment from factors such as solar radiation, enthalpy humidity, and wind direction. Geomagic Qualify 2013 software was used to generate a rainbow map to analyze the causes of pathology on the heritage structure and materials. After comprehensive analysis, reasonable pathology prevention and control measures are suggested, aiming to fortify the sustainable preservation of architectural heritage.

## 3. Materials and Methods

### 3.1. Materials

#### 3.1.1. Study Area

Wuhan, situated in the heart of China within Hubei Province, boasts a strategic location adjacent to the Yangtze River and offers excellent transportation infrastructure (Figure 1a,b). On the opening of Hankou as a port in 1861, Wuhan became an excellent missionary area for missionaries, attracting many churches and scholars to establish schools there. In addition to introducing new educational models, Western churches also introduced new building types [28]. This article collects historical materials and conducts field research on more than 70 existing educational architectural heritage properties in Wuhan from 1861 to 1949. The research finds that the James Jackson Gymnasium of the Boone Memorial School, located in the Wuchang District of Wuhan (Figure 1c,d), is one of the earliest indoor stadium buildings in China. It holds significant historical and artistic value in the history of modern Chinese architecture [29]. At present, the James Jackson Gymnasium is an important base for displaying and promoting Wuhan urban culture [30], serving as a traditional culture and traditional Chinese medicine culture exhibition center, Tanhualin Han Embroidery Exhibition Center, Wuchang International Fashion Release Center, etc. This historical building is an important representative in Wuhan. This article takes the James Jackson Gymnasium as the main research object, conducts a systematic study on its building pathology information, and extends it to other educational architectural heritage from point to point.

#### 3.1.2. Data Collection

The data in this article come from "Historical Research on Modern Educational Buildings in Wuhan" and "Census of Modern Educational Building Heritage in Wuhan". Starting in 2018, the research team of Professor Wang Hechi of the Hubei University of Technology conducted a systematic survey of modern educational buildings in Wuhan, collected historical data, and constructed a database of modern educational buildings in Wuhan. The sources of historical data are divided into two categories. One is the Wuhan Municipal Archives, Wuhan Municipal Education Chronicle, Wuhan Municipal Excellent Historical Building Protection Plan and school history materials of various schools in Wuhan, including historical maps, photos of historical buildings, drawings of historical buildings, documents of historical buildings, etc. The other category comes from related works [31], such as "Modern Educational Architecture in Wuhan [32]" (Chen Libo, Xu Yusu, Yu Gege), "Overview of Modern Chinese Architecture in Wuhan [33]" (Liu Xianjue, Zhang Fufu, MURAMATSU Shin, etc.), "Modern Wuhan Urban History [34]" (Pi Mingxiu), etc. Between 2018 and 2022, we conducted on-site research and mapping of Wuhan's modern educational architectural heritage, including on-site photos, architectural mapping, interviews with relevant personnel, etc.

The statistics of modern educational architectural heritage in Wuhan are as follows (Table 1).

In the above table, according to the classification of building structure forms, there are 55 heritage sites in the form of brick and wood structures, 12 in reinforced concrete structures, and 7 in masonry structures. Among them, the heritage with brick and wood structures account for the majority, comprising 84% of the total. Therefore, this article chooses the James Jackson Gymnasium, a historical building with brick and wood structure and high heritage level, as a typical case study [28].

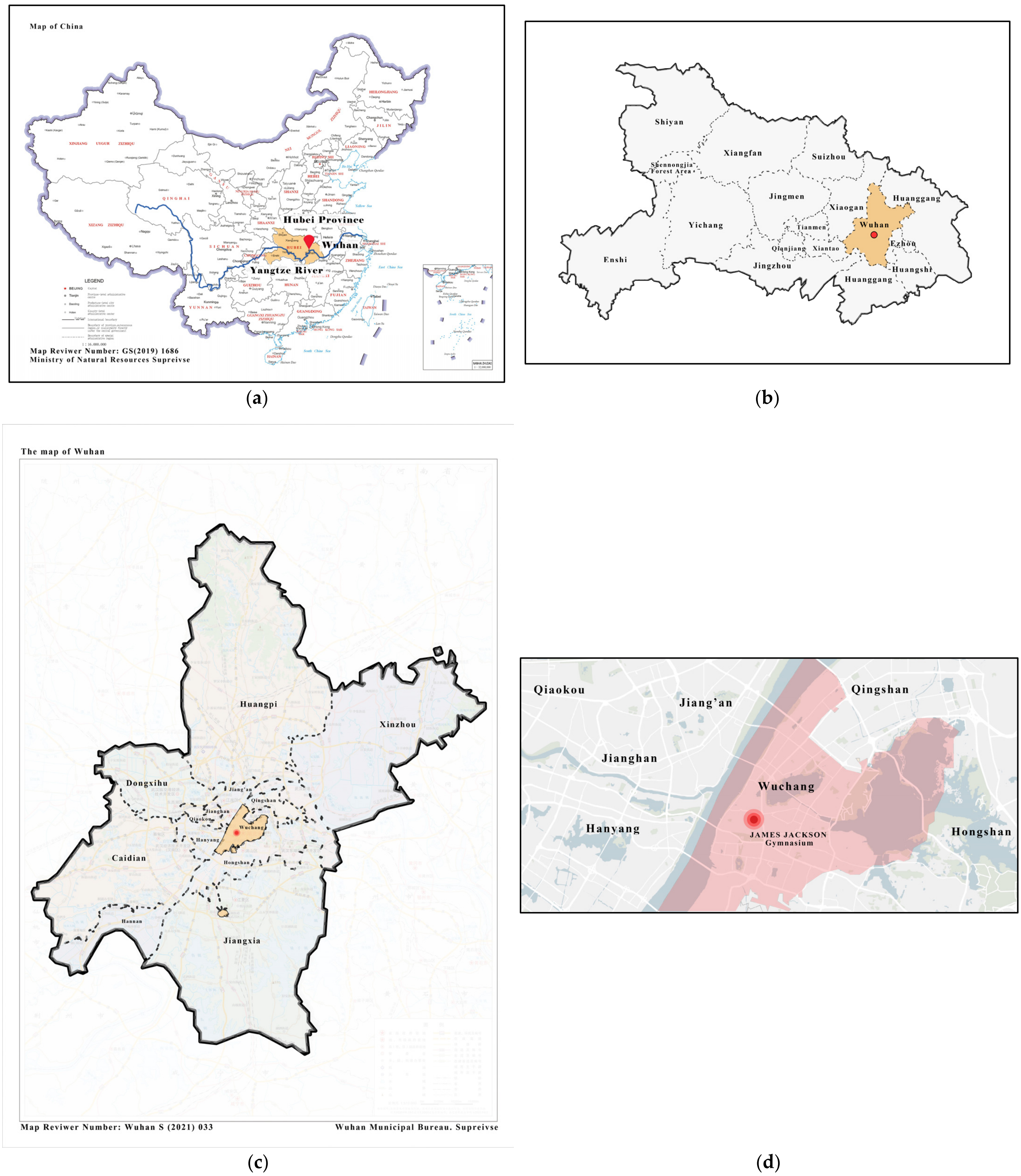



**Figure 1.** (**a**) Location of Hubei Province in China. (**b**) Location of Wuhan in Hubei Province. (**c**) Location of Wuchang district in Wuhan. (**d**) Location of James Jackson Gymnasium. Base map source: Standard Map Service (https://www.resdc.cn, accessed on 30 September 2023).

**Table 1.** Statistics of modern educational architectural heritage in Wuhan (source: [7]).

| Distribution Area | Heritage Statistics | Heritage Name | Number of Heritage Items on Campus | Location | Age |
|---|---|---|---|---|---|
| Wuchang | 64 | Boone Memorial School | 7 | No. 110 Yunjiaqiao, Wuchang District | 1871. |
| | | London Mission Hospital for Men/Women in Wuchang | 1 | No. 4 Huayuanshan, Wuchang District | 1895. |
| | | Wuchang Shandao Girls' Senior School | 2 | No. 116 Shouyi Road, Wuchang District | 1936. |
| | | San Garn Girl's Middle School | 1 | Fuxing road, District Wuchang | 1912. |
| | | Boone School | 1 | No. 71 Liangdao Street, Wuchang District | 1871. |
| | | Gude Girl's Middle School | 1 | No. 101 Tanhualin, Wuchang District | 1897. |
| | | Truth Middle School | 3 | No. 115 Tanhualin, Wuchang District | 1890. |
| | | St. Hillida Women's Middle School | 3 | No. 444 Wuluo Road, Wuchang District | 1911. |
| | | Bowen College | 8 | No. 257 Wuluo Road, Wuchang District | 1904. |
| | | Early Buildings of Wuhan University | 11 | Luojia Hills, Wuchang District | 1928. |
| | | Wuhan University Kindergarten | 3 | Luojia Hills, Wuchang District | 1936. |
| | | Primary School Affiliated to Wuhan University | 4 | Luojia Hills, Wuchang District | 1945. |
| | | Wuhan High School | 4 | No. 275 Liangdao Street, Wuchang District | 1920. |
| | | Hubei Provincial Library | 1 | No. 45 Wuluo Road, Wuchang District. | 1936. |
| | | Lianghu Academy | 3 | No. 259 Jiangfang Road, Wuchang District | 1927. |
| | | Wuchang Higher Normal School Attached Primary School | 3 | No. 69 DuFuDi, Wuchang district | 1913. |
| | | North Road School (Peasant Movement Institute) | 6 | No. 13 Hongxiang, Wuchang District | 1927. |
| | | Hubei Women's Vocational High School | 1 | No. 32 Tanhualin, Wuchang District | 1913. |
| | | Provincial No. 1 Middle School | 1 | No. 141 Tanhualin, Wuchang District | 1912. |
| Hankou | 8 | Boxue Middle School | 3 | No. 171 Jiefang Boulevard, Qiaokou District | 1905. |
| | | Dehua Shutang | 1 | No. 64 Qiuchang Street, Jiang'an District | 1908. |
| | | St. Joseph's School | 1 | No. 222 Zizhi Street, Jiang'an District | 1925. |
| | | British Primary School | 1 | No. 16 Tianjian road, Jiang'an District | 1911. |
| | | Hankou Women's Middle School | 1 | Simin Street, Hankou District | 1930. |
| | | Hankou Saint Roui Girl Middle School | 1 | No. 52 Hezuo Road, Jiang'an District | 1931. |
| Hanyang | 2 | Xunnv Middle School | 1 | No. 24 Beicheng Lane, Hanyang District | 1936. |
| | | Wuhan No. 3 Middle School | 1 | Sixin North Road, Hanyang District | 1945. |
| Total | | 74 | | | |

*3.2. Methods*

The method flow chart of this article is shown below (Figure 2). The work process is divided into the following four stages:

(1) Gather information; (2) Construct 3D model; (3) Creating pathology information database; (4) Analyze the causes of pathologies.

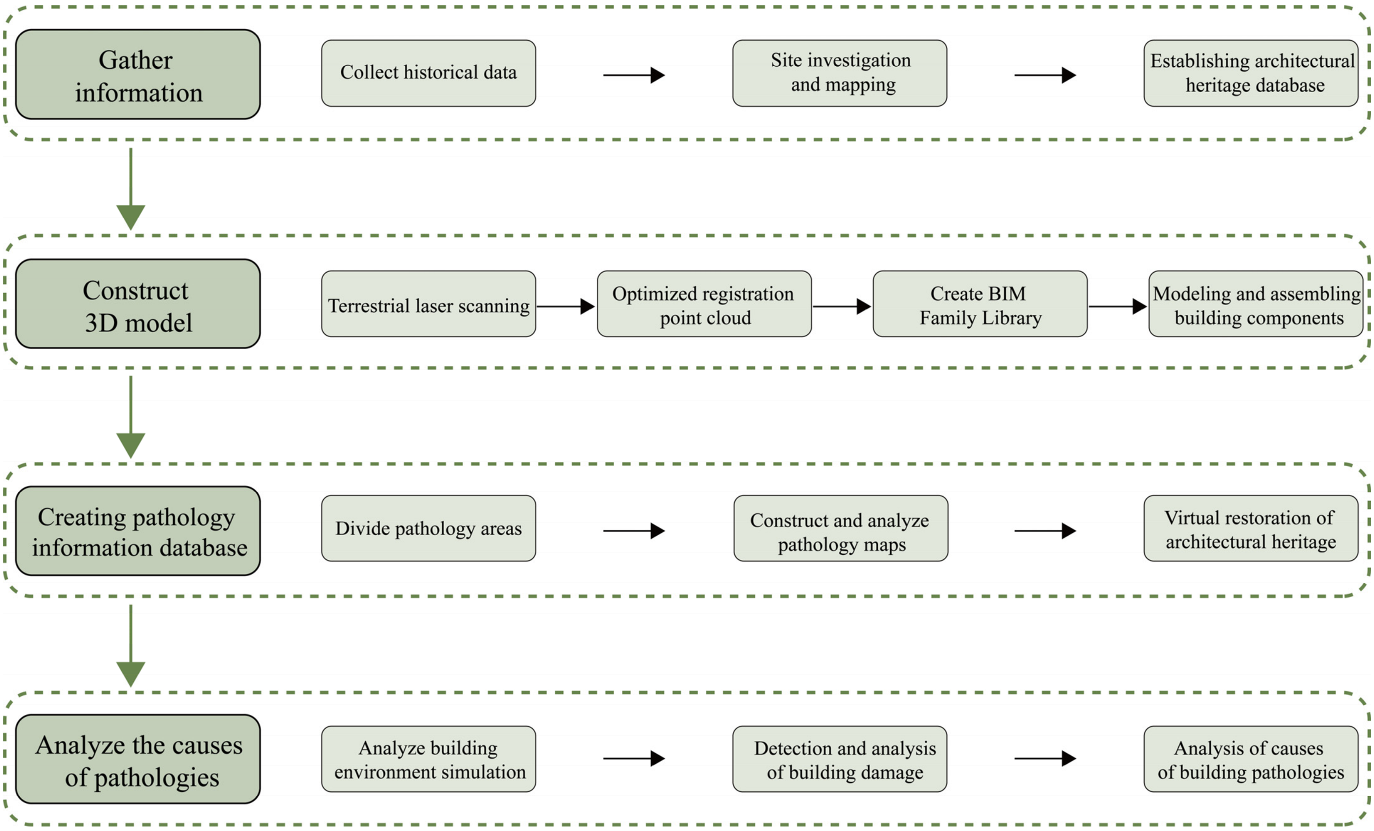



**Figure 2.** Work flow (source: author).

3.2.1. Research Methods

This article first uses 3D laser scanning to collect the physical information and pathology information of a historical building and uses register360 1.0 to splice the 3D scanned point cloud data and images; then, DP-Modeler 3.0 three-dimensional modeling software to process the obtained point cloud data to generate a refined 3D spatial information of historical buildings, followed by import into Revit to establish a parametric component family to form a BIM model and build a three-dimensional information model and current situation model of the historical building based on drawings, photos, and measurement data [35], focusing on the pathology information of historical buildings in the BIM model, and dividing the pathology areas corresponding to the actual pathology photos. At the same time, the historical building pathology map is generated through the BIM schedule function to provide basic data for later preventive protection and maximize the visual management of pathology. Finally, Ecotect 2011, Geomagic Qualify 2013 and other software are used to simulate the environmental factors caused by the historical building pathology and the damage condition of the building itself and to analyze the causes of the pathology.

- Three-dimensional laser scanning

Three-dimensional laser scanning is a fully automatic, non-contact, high-precision three-dimensional scanning technology. A large amount of point cloud data on the surface of the measured object are collected through cloud measurement technology [36], and the spatial information and color/grayscale information of the measured target point are recorded [37]. The advantages of 3D laser scanning are: 1. Non-contact measurement, reducing secondary damage to historical buildings. 2. High data collection efficiency and strong real-time performance. 3. High precision, with errors reaching millimeter levels, and the ability to describe the details of objects in detail. 4. Fully digital characterization, high degree of automation, easy information transmission, processing, expression, and convenient operation. Even though the accuracy of current 3D laser scanners is very high, it is still necessary to strictly ensure that the measurement method of the scanning instrument is accurate to ensure the accuracy of the scanning results [38,39].

This article uses the Leica BLK360 three-dimensional laser terrestrial scanner made in Wuhan, China by Leica Geosystems. The Leica BLK360 3D laser scanner can quickly and accurately acquire 3D spatial information on construction sites and can quickly acquire 3D spatial point cloud information and 360° panoramic images within 3 min. The IE browser can be used to view on-site data anytime and anywhere, and Leica Cyclone Register 360 1.0 and Cloud Worx for Revit 1.1 software can be used to realize intelligent splicing and intelligent matching of point cloud data. The software can be seamlessly connected with construction software such as AutoCAD 2018, Revit 2020, and etc. Its measurement system can not only provide a full lifecycle measurement solution for BIM, but also provide basic data for digital archiving, three-dimensional modeling, dimensional measurement, information sharing, etc., of historical buildings and architectural pathology.

- BIM modeling

BIM (Building Information Modeling) integrates various information resources throughout the lifecycle of the engineering project into a database by establishing a virtual three-dimensional information model [40]. This article applies BIM to the protection of historical buildings and pathology information management. The scanned point cloud data are imported into Revit 2020 software, including building component dimensions, materials, pathology information, etc. Since Revit does not have automatic object recognition tools, creating a parametric 3D restoration model requires a manual process. At the same time, the rendering of virtual models of historical buildings is realized. Obtaining detailed two-dimensional drawings through Revit's plan, elevation and other viewing functions, provides better solutions for the repair and protection of historical buildings. This is the basis for pathology analysis and prediction of historical buildings.

- Computer simulation

Autodesk Ecotect Analysis 2011 software is a sustainable design and analysis tool that can visualize and simulate building performance in the real environment and simulate the impact of sunlight, wind, shadow, radiation, and other factors on the environment [41]. Ecotect analysis models can be imported after modeling in Revit. This article first exports the Revit model to DXF format, realizes data exchange between Revit 2020 and Ecotect 2011 through DXF format, and then imports the DXF format model into Ecotect 2011 software, so that the imported data can be kept intact. This article uses Ecotect 2011 software to simulate hourly meteorological parameters, such as temperature, relative humidity, wind direction, wind speed, wind frequency, solar radiation, etc., to analyze the relationship between the external environment and historical building pathology.

Geomagic Qualify is a professional reverse-verification software commonly used in the field of industrial product manufacturing at this stage. It can generate a rainbow map (elevation deviation analysis chart) through a precise 3D comparison of two models and identify differentiated areas and deviation values. In the field of historical building protection and repair, it is used to compare with idealized models to find deformations, deviations, and other components that can easily cause building damage [42]. This article uses this software to make a detailed comparison between the scanned point cloud model and the Revit model, explore the damaged parts of historical building pathology, and identify and analyze the deviation values of the building's pathology parts. This method can conduct pathological analysis of historical buildings intuitively, accurately, and effectively [43].

3.2.2. Research Path Design

This article first constructs a modern education heritage database in Wuhan by collecting historical data and onsite research. Then, taking the James Jackson Gymnasium as a typical case, through historical research and onsite three-dimensional scanning, a BIM information database was established to establish the pathology information model, pathology details, and virtual repair of pathologies of the building components. Finally, Autodesk Ecotect Analysis 2011 software is used to generate hourly meteorological parameters, and the relationship between the external environment and the pathology of the historical building is simulated and analyzed. Using Geomagic Qualify 2013 software to explore the damaged parts, damaged pathology information and deviation value analysis of historical building pathology, and comprehensively to explore the causes of the formation of pathology, the research idea proceeds as follows (Figure 3).

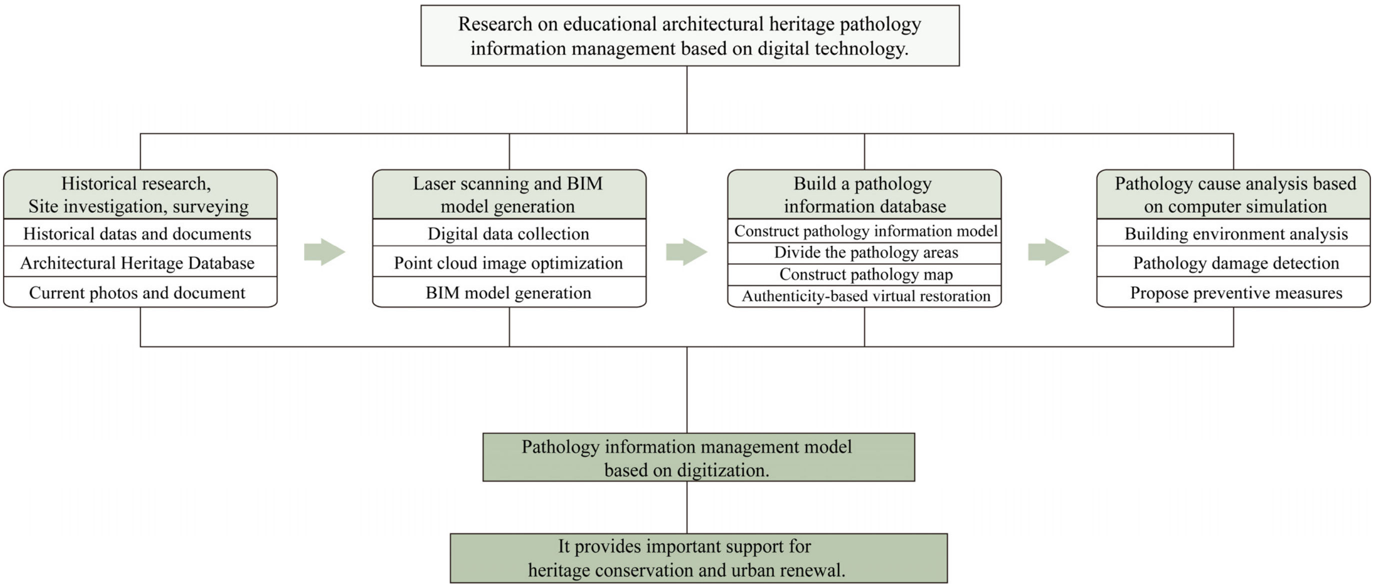
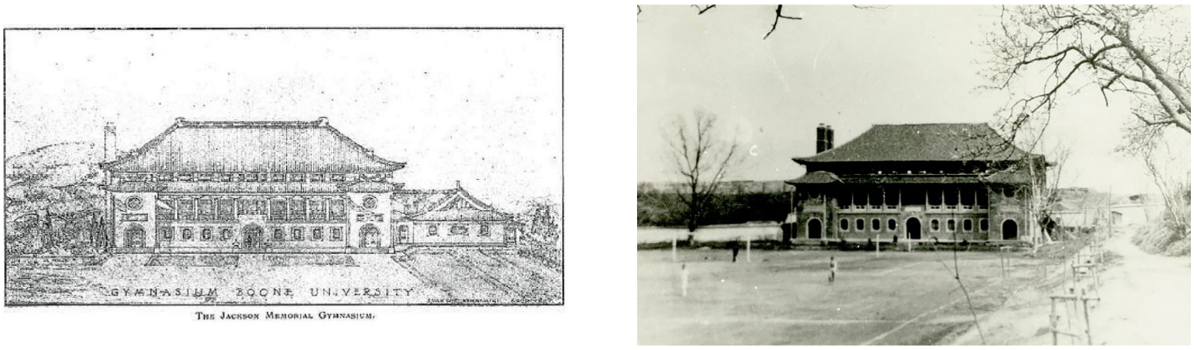



**Figure 3.** Research Framework (source: author).

## 4. Results

### *4.1. Historical Research and Site Surveying*

This article selects the James Jackson Gymnasium, a typical case of modern educational architecture in Wuhan, for a comprehensive, in-depth, and systematic analysis. The Gymnasium serves as the gymnasium of the Boone Memorial School (the predecessor of Central China Normal University). The building was originally named the Jackson Memorial Gymnasium and is now called the James Jackson Museum. Erected in 1921 (Figure 4a,b), it has a history of about 100 years and was named in memory of James Jackson, the first president of the Boone Memorial School [44]. It is one of the earliest indoor stadium buildings in China and the only remaining double-story brick timber mixed structure building in Wuhan. In 1993, it was included in the first batch of "Excellent Historical Buildings Class II Protected Buildings" in Wuhan.




(a) (b)

**Figure 4.** Historical pictures of James Jackson Gymnasium (source: [45]). (**a**) The James Jackson Gymnasium's design drawings in 1921. (**b**) Historical photo of the building.

The building was designed by the American missionary J. Van Wie Bergamini. This structure stands as one of the earliest amalgamations of Chinese and Western architectural styles in contemporary China. In addition, it is the oldest existing gymnasium in Wuhan architecture. It is an avant-garde exploration of Western structure and Chinese form and plays an enlightening and leading role in the revival of traditional Chinese architecture [46]. Its roof adopted the double-eave hip roof form of traditional Chinese architecture, which has the typical characteristics of a combination of Chinese and Western styles.

The building is located on today's Tanhualin Historical and Cultural Street, Wuchang District, next to the playground on the west side of the Hubei University of Traditional Chinese Medicine gate. The building area is about 1000 square meters, the bay is about 27.95 m, the depth is about 16.59 m, and the height is about 14.85 m. There is an arch door in the middle of the first floor of the main facade, and there are four square windows on the left and right with square cement window covers (Figure 5a). The building facade is made of red brick walls and is not painted (Figure 5b). The outer corridor on the second floor is a traditional Chinese architectural form [45], with beam and queti (queti is an object placed on the upper end of the column to bear the upper pressure together with the column and is located at the junction of the beam and the column or the fang and the column); and a fang (a fang is a horizontal or vertical plug-in member that serves as a connection and stabilization point between the pillars). There are column bases and railings underneath and Chinese-style railings between the columns. They are all made of concrete. The doors and windows all adopt the construction form of traditional southern Chinese houses, and the window lattice comes in various forms.

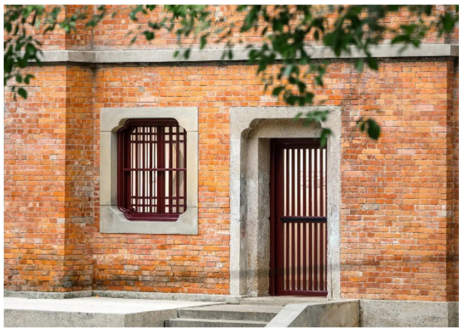
The first floor of the building is used as an exhibition space, and the second floor uses a steel-timber hybrid beam frame to form a large-span column-free indoor space that can be used as a gymnasium (Figure 5c). There are stairs at the left and right ends of the building and corridors at the north and south sides. The roof is equipped with skylights for lighting and is covered with green glazed tiles (Figure 5d).

After renovation in the 1980s, the building served as an indoor gymnasium until 2016. From 2015 to 2016 [47], the function of the building was changed from a gymnasium to a museum (Figure 6a,b).

### 4.2. Laser Scanning and BIM Model Generation

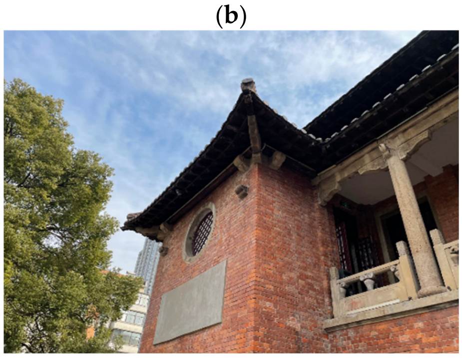
The geometric precision and accuracy of BIM models are directly related to the information integrity and authenticity of historical buildings, which is a key discussion topic among workers engaged in the architectural heritage protection industry. Even though, currently, due to algorithm limitations, 3D laser scanning is still unable to directly extract vector data for automatic modeling using point cloud data, it has helped practitioners in their modeling work to a great extent [48]. Although 3D scan data are not shareable, BIM solves this problem very well [49]. BIM can achieve a high degree of integration of all relevant data of the project. The BIM model has the characteristics of high three-dimensional visualization and strong information integration capabilities [50]. Therefore, this article combines the advantages of BIM technology and 3D scanning technology, uses 3D scanning technology to obtain architectural model information, uses the Revit modeling platform to create a parametric component family library, and builds a 3D information digital model of historical buildings.

(**a**)



(**b**)

(**c**)



(**d**)

**Figure 5.** Detailed components (source: author). (**a**) Main facade of building. (**b**) Building exterior wall. (**c**) Building indoor, second floor. (**d**) Building eaves and corridors.

(**a**)

(**b**)

**Figure 6.** James Jackson Gymnasium's current situation (source: author). (**a**) Current status of the main facade of the building. (**b**) Current status of the north facade of the building.

### 4.2.1. Digital Data Collection

During the three-dimensional laser scanning process, we fully considered the surveying and modeling needs of two-dimensional plans, sections, and building components, and set measuring points reasonably to provide accurate data for later modeling. Through 3D laser scanning technology, 3D point cloud data on the surface of an object can be obtained quickly, over a large area, with high efficiency, and in a non-contact manner, providing a basis for subsequent construction of BIM information models [51].

We conducted a three-dimensional laser scan of the James Jackson Gymnasium on 19 September 2023, obtained laser point cloud data, and conducted supplementary scans and mapping on 23, 25, and 28 September 2023. This article uses the Leica BLK 360 three-dimensional laser scanner. Table 2 lists the scanner configuration information. The complete number of scans is approximately 200 registrations.

**Table 2.** The scanner configuration information (source: author).

| Instrument | Weight [kg] | Range [m] | Range Accuracy | Field of Vision [°] |
|---|---|---|---|---|
| Leica Geosystem BLK360 | M = 1 | 0.6 < S < 60 | 4 mm @10 m<br>7 mm @20 m | 300 V<br>360 H |

The surveying and mapping process is as follows:

Starting from the north facade of the first floor of the building, scan station-by-station in a clockwise direction, and arrange a total of 21 scan stations. Adjacent scan stations ensure that there is at least 40% overlap of the same image of the point cloud to facilitate image splicing for three-dimensional modeling. During on-site surveying and mapping, we arranged three scan stations on each of the east and west sides of the historical building and five scan stations on each of the south and north sides (Figure 7a,b), ensuring that the range of every two points is between 5–10 m.

(**a**) (**b**)

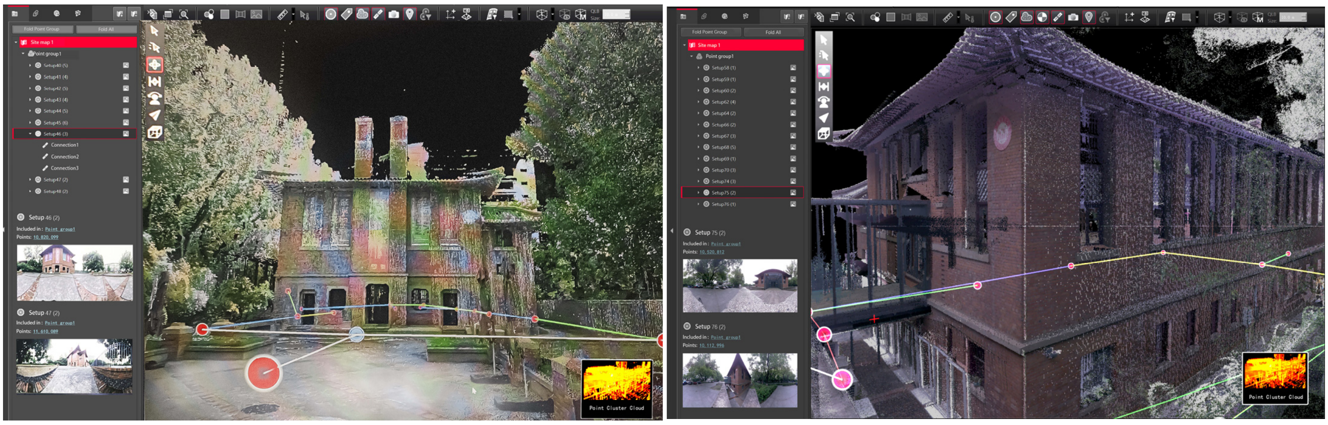
**Figure 7.** Surveying and mapping (source: author). (**a**) Three-dimensional scanning mapping photo. (**b**) Three-dimensional scanning mapping photo.

### 4.2.2. Point Cloud Image Optimization

Errors due to surface texture, defects, etc., of the object being measured, or accidental factors such as vehicles, pedestrians, and birds entering the scanning area when scanning buildings, are the main causes of noise during the scanning process. Therefore, noise reduction processing is required for the spliced point cloud to effectively improve image accuracy [52].

First, this article uses Register360 1.0 point cloud processing software linked to Leica for splicing and uses the software's own tools to filter point cloud noise. Point cloud data splicing adopts the ICP algorithm, with the help of the error function to reflect the degree of intersection in the overlapping area of the point cloud. The least square method is used to perform iterative operations to achieve the optimal solution of coordinate transformation, and finally the minimum value of the measurement error is obtained to ensure the accuracy of point cloud splicing data [53]. It is ensured that the overlap degree of each point cloud splicing reaches 40%, and the point group error is within 0.015 m.

Then, after the splicing is completed, the gap between the point cloud data is small, and the registered and spliced historical building point cloud model is roughly similar to the actual historical building shape, and there are no obvious problems such as damage, deviation, and misalignment [54]. The processed point cloud is saved to obtain point cloud data in LAS format (Figure 8a,b). The color of the line in the figure represents the matching quality, and the position of the circle represents the point cloud position.



(**a**) (**b**)

**Figure 8.** Preprocessed point cloud data result map (source: author). (**a**) North facade point cloud data. (**b**) Southeast facade point cloud data.

Finally, the point cloud data are imported into the 3D modeling software DP-Modeler 3.0, and the point cloud information is converted into 3D spatial information through the computing function of the software, so that a high-definition 3D spatial model can be quickly generated. Since it is an area model obtained through point cloud scanning, the current status of the pathology information will be recorded, which is conducive to comparison work such as monitoring the development and changes of the pathology information (Figure 9a,b).

(**a**) (**b**)

**Figure 9.** Three-dimensional spatial information renderings (source: author). (**a**) Perspective view of the southwest side of the building. (**b**) Perspective view of the second-floor corridor.

#### 4.2.3. BIM Model Generation

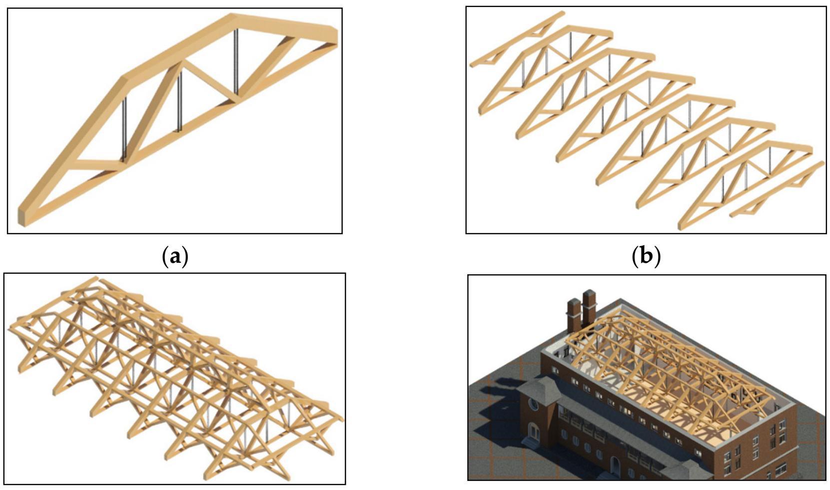
The method used was as follows: import the point cloud data into CAD and use the point cloud data as a reference to draw building component information such as walls, columns, stairs, etc., to obtain the plan, elevation, and section views of the building; then, use the above plan, elevation, and section views as reference images to build a BIM model in Revit 2020 software. This method ensures that the property information and spatial information of building components are complete, providing a basis for later building pathology information recording and pathology visual analysis.

When using Revit to build a BIM three-dimensional model, creating a component library can improve efficiency. The method of creating a component library is as follows: When using Revit's volume modeling, family libraries such as "column family", "beam family", and "wall family" are formed for different building components. This can reduce the repetitive work of modeling the same component. Then, the component table of the building is drawn based on these component dimensions (Table 3).

**Table 3.** List of building facade components (source: author).

| Classification | Family and Type | Height /Thickness (mm) | Volume/m$^3$ |
|---|---|---|---|
| Pillar family | Column 1: 300 × 300 mm | 4000 | 0.64 |
| | Column 2: 300 × 300 mm | 5000 | 0.80 |
| | Square column 1: 230 × 230 mm | 4000 | 0.22 |
| | Square column 2: 230 × 230 mm | 5000 | 0.27 |
| Girder family | T-section beam 1: 500 × 450 mm | 15,700 | 3.53 |
| | T-section beam 2: 500 × 450 mm | 17,500 | 3.93 |
| Door family | Double paneled wooden door 1: 1800 × 2100 mm | 50 | 0.20 |
| | Double paneled wooden door 2: 1800 × 2100 mm | 50 | 0.25 |
| | Single-panel glass door 1: 700 × 2100 mm | 50 | 0.07 |
| | Double-swing door 1: 1200 × 2100 mm | 50 | 0.13 |
| Window family | Casement window 1: 700 × 1500 mm | 80 | 0.08 |
| | Casement window 2: 1200 × 1500 mm | 80 | 0.14 |
| | Casement window 3: 1500 × 1800 mm | 80 | 0.22 |
| | Round fixed window 1: 1200 × 1200 mm | 60 | 0.08 |
| Queti family | Queti 1: 240 × 440 mm | 50 | 0.005 |
| | Queti 2: 250 × 250 mm | 50 | 0.003 |

The building's roof truss structure system is very complex, and we used this as an example to build a three-dimensional model (Figure 10) of a steel-wood composite roof truss. First, a roof truss is made to form a "roof truss family" component library. Then, after arranging the multiple roof trusses in order, the multiple roof trusses are connected in series using tie beams to form a load-bearing system of the roof truss structure. Finally, the roof truss structure is placed on the support points of the wall, thus forming the structural system of the roof truss. This also shows that the roof load and the self-weight of the roof truss are mainly borne by the wall.



(**a**) (**b**) (**c**) (**d**)

**Figure 10.** Three-dimensional model of beam frame family (source: author). (**a**) A roof truss. (**b**) Multiple roof trusses. (**c**) Tandem roof trusses. (**d**) Arrangement of roof trusses.

This article is based on the modeling of building components such as “floor surface—walls—beams and columns—doors and windows—roof trusses”. After completing the model of each building component, the outer contour points of the building are superimposed to form a complete James Jackson Gymnasium BIM building model (Figure 11). It records in detail the component dimensions, building area, bay depth, and overall height of the James Jackson Gymnasium (Figure 12).

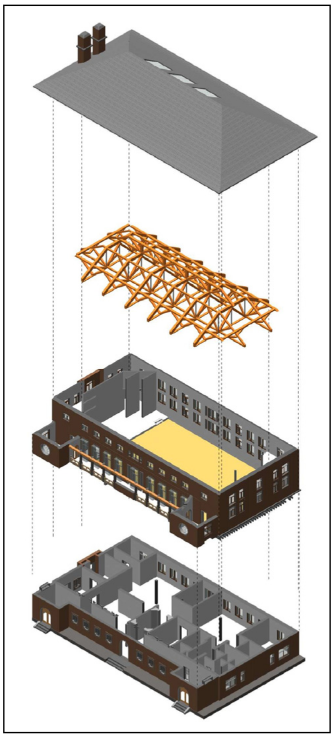


**Figure 11.** Disassembly drawing of building components (source: author).

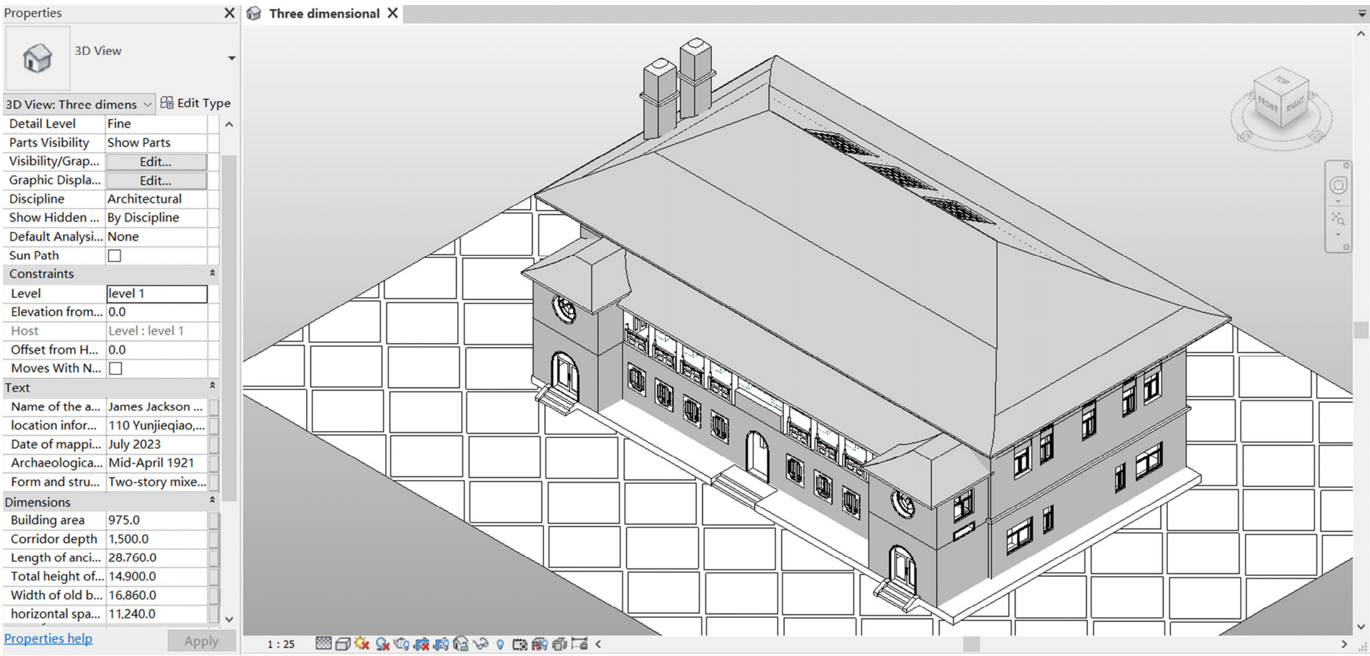



**Figure 12.** James Jackson Gymnasium 3D model information integration diagram (source: author).

### *4.3. Build a Pathology Information Database*

This article constructs an "electronic record" of historical buildings, which not only facilitates the protection and management of historical buildings but also provides powerful data support and reference for future restoration of historical buildings. Comprehensive real-time monitoring of pathology parts of historical buildings is the focus of this study. Traditional pathology detection mainly focuses on taking pictures and writing down the pathology parts, but this method is both inefficient and contains detection errors.

This article uses three-dimensional laser scanning technology and pays special attention to pathology information in the scanned point cloud data. The three-dimensional model generated by DP-Modeler 3.0 software can be used to view the pathology status of the building in an all-round way. Then, the collected pathology information is added to the BIM model, and the pathology area is divided according to the position of the pathology information in the model to achieve visualization of the pathology area in the BIM model. Finally, map management and virtual repair are carried out based on the pathology status of the BIM model, providing a reference for subsequent repairs of historical buildings.

#### 4.3.1. Construct Historical Building Pathology Information Model

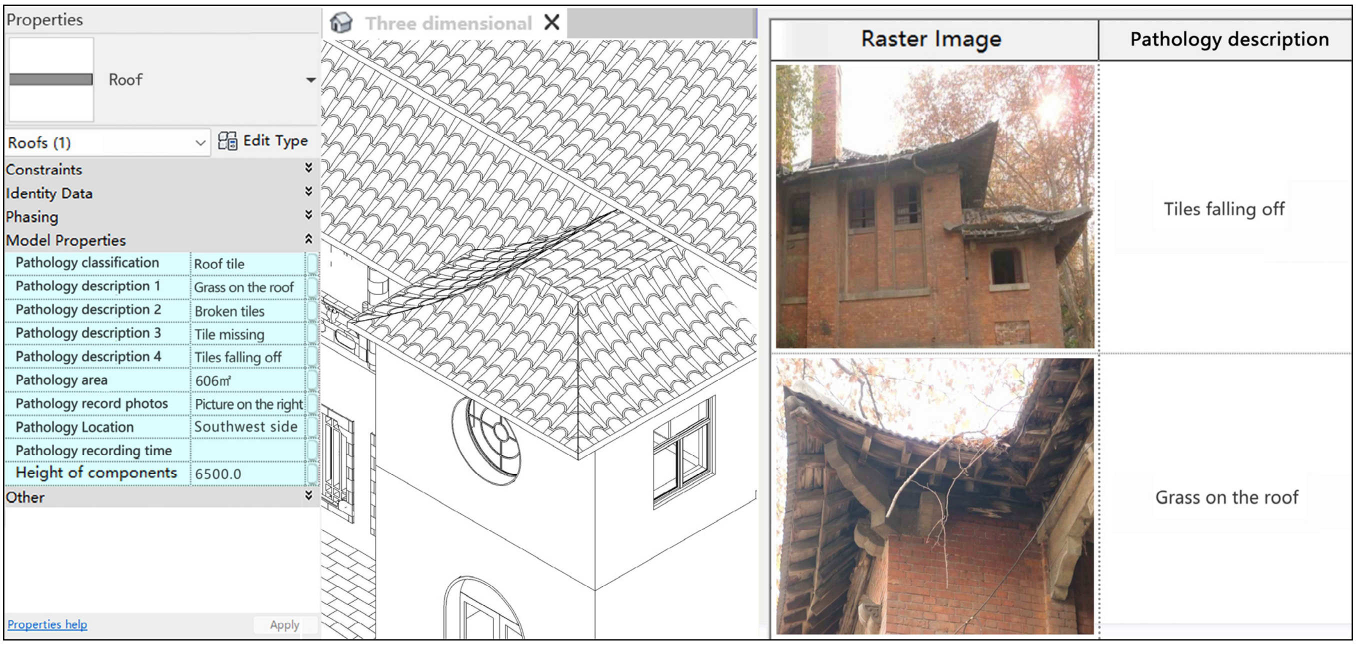
In order to analyze the dynamic evolution trend of historical building pathologies, in the BIM pathology information model we classify the pathology information of different parts of the building according to the pathology development trend. By adding "Building Pathology Shared Parameters" in Revit, including five parts of parameter information such as "Pathology Classification", "Pathology Description", "Pathology Area", "Pathology Current Photos", and "Pathology Documents", the pathology information and development trends of each component can be viewed in the model from all directions and from multiple angles. According to the pathology locations of building components, this article divides the pathology information into six parts: "tile roof, wood roof truss, wall, beam column, door and window, and floor surface", and constructs a systematic pathology information database.

First, by attaching the pathology location, pathology size, pathology photos, pathology text records, etc., to the three-dimensional model, we comprehensively displayed the damage, cracking, weathering, and other pathology states of the building components. Then, we classified the pathologies and recorded the time of the pathology in the "shared parameters". Finally, an integrated map of historical building pathology information was generated to realize real-time monitoring of the historical building pathology. For example: the roof of James Jackson Gymnasium is covered with grass and the tiles are damaged (Figure 13a), the wood roof trusses are rotten and cracked (Figure 13b), the stone window sills are weathered (Figure 13c), and the platform base and wall are corroded (Figure 13d). In this way, we built a three-dimensional model of the pathology information of different parts of the historical building in the Revit 2020 software according to the timeline to realize the visualization of the pathology information of the historical building.

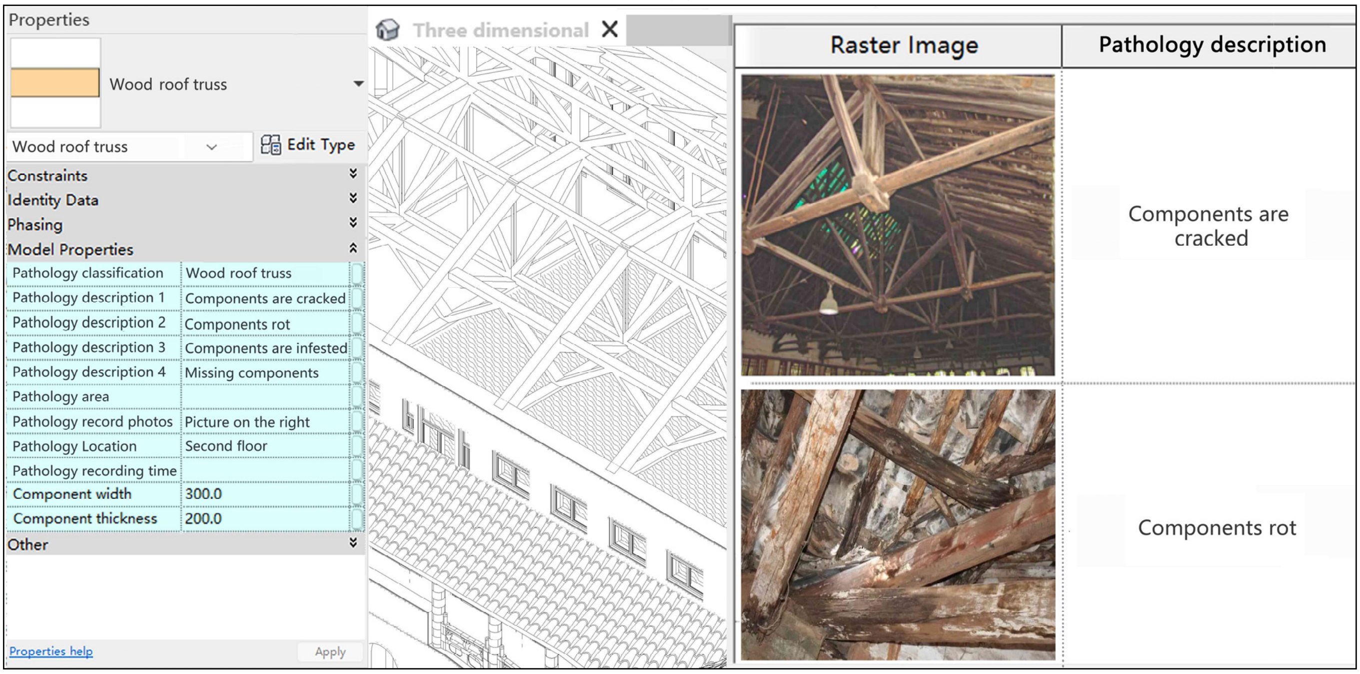
It can be seen from Figure 13 that the brick walls, wooden roof trusses, columns, and other structural components of the building are seriously damaged, and the monitoring and protection of these important parts should be strengthened.

#### 4.3.2. Divide the Pathology Areas of the BIM Model

In order to more clearly understand the location and details of historical building pathologies, we distinguish the areas where the pathologies occur to realize regional visualization of BIM pathologies [55]. We use the "Room Separation" function in the BIM model to divide specific pathology areas and add descriptions and pathology photos according to the pathology status, using different colors or patterns to differentiate between different areas and causes of pathology, as shown in Figure 14, which shows the locations of various pathologies on the first floor of the James Jackson Gymnasium. Through this plan, we can understand the entire pathology status of historical buildings, facilitate quick identification of the specific location of the pathology, and monitor the development trend of the pathology, so that staff can find problems in time and provide a reference for the repair of historical buildings.

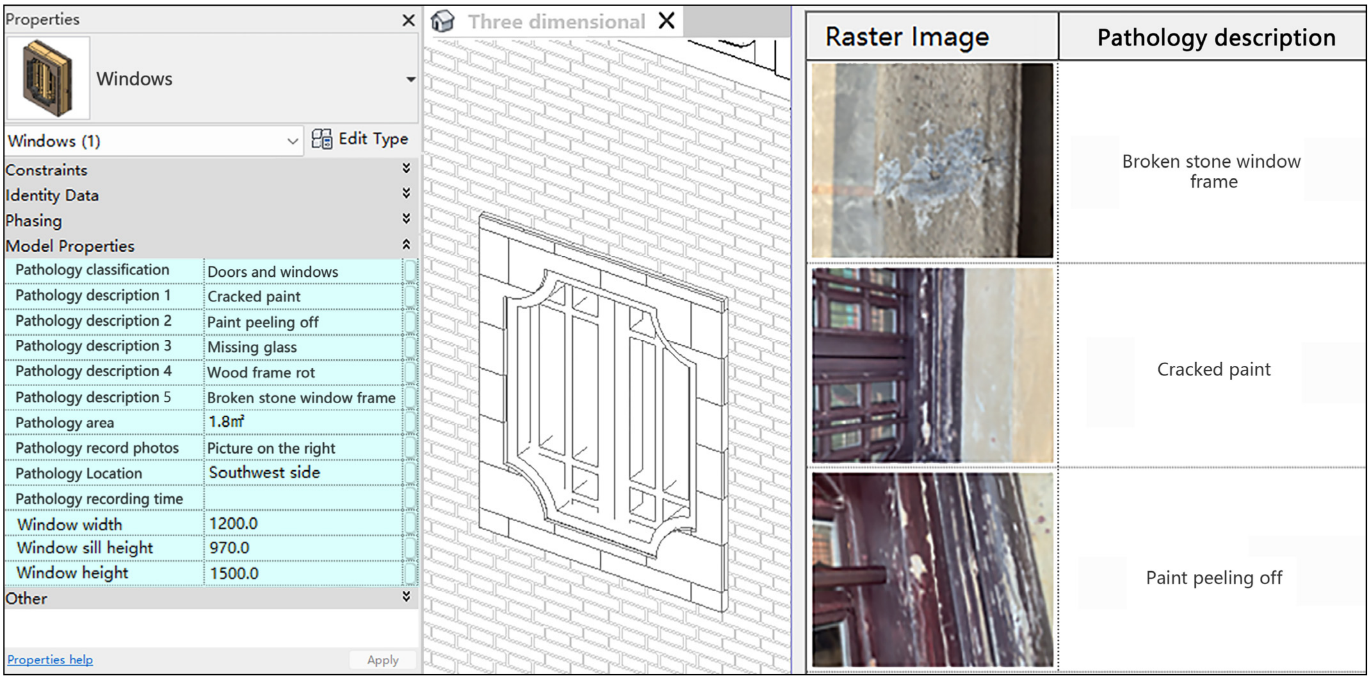



(**a**)

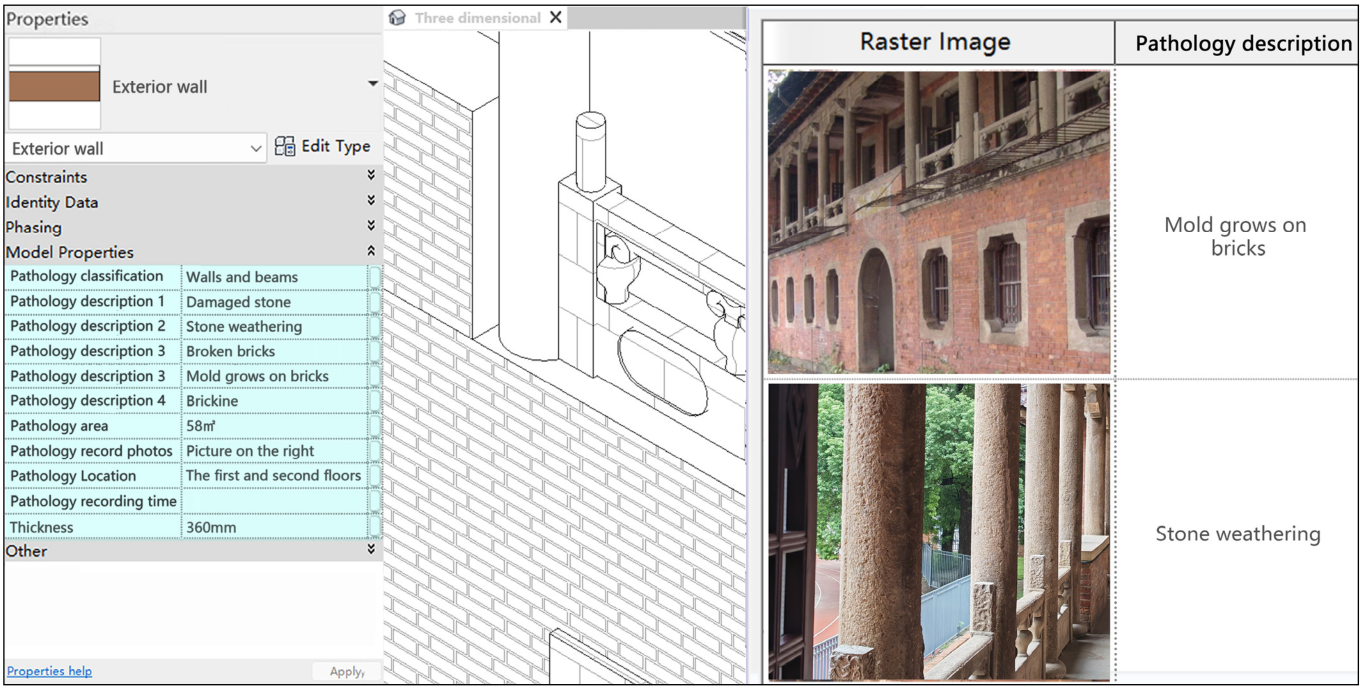



(**b**)

**Figure 13.** *Cont.*




(**c**)




(**d**)

**Figure 13.** Integrated diagram of James Jackson Gymnasium pathology information (source: author). (**a**) Roof tiles component pathologies. (**b**) Wooden roof truss component pathologies. (**c**) Door and window component pathologies. (**d**) Wall components pathologies.


**Figure 14.** Visualization of building pathology areas (source: author).

#### 4.3.3. Construct and Analyze BIM Pathology Map

This article draws on the ideas of the internationally renowned MDDS (Monument Damage Diagnostic System) cultural relic damage diagnosis system to conduct pathology map management of the BIM model of the historical building [56], classifying the pathology information of various materials such as brick walls, wood, concrete, and tiles that are common in historical buildings, and using Revit's detailed list function to generate a detailed list of pathology information. According to the detailed chart, the percentage of various types of building pathology areas is summarized (Figure 15).

The sources of pathology area and percentage of pathology area are as follows:

The image exported by the 3D laser scanner can calculate the area of the image through relevant algorithms and obtain the area size of the building surface, the component itself, and the pathology area. The proportion of the building pathology area is calculated based on the connected-domain principle, and the area of the building pathology area is obtained [57]. For example, we calculated that the moldy area in areas prone to moisture, such as steps and walls, accounts for more than 30%; the weathering of stone window frames accounts for 11%. It is speculated that the cause of the pathology is natural factors, such as moisture or sun exposure.

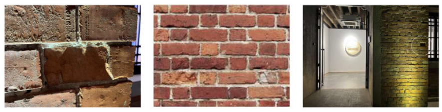
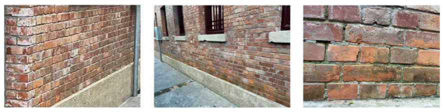
| Pathology classification | Pathology description | Pathology area/㎡ | percentage/% | Picture |
|---|---|---|---|---|
| Floor | Floor erosion and discoloration | 1.32 | 5 |  |
| First-floor exterior wall | Damaged wall | 4.55 | 1 |  |
| First-floor exterior wall | Brick wall soft and falling off | 88.84 | 10 |  |
| First-floor exterior wall | Mold on the wall | 14.38 | 10 |  |
| Interior wall | Wall color turns black | 11.8 | 1 |  |
| Stone steps | Broken steps | 0.96 | 5 |  |
| Stone steps | Steps cracked | 5.42 | 10 |  |
| Stone steps | Mold on the steps | 2.87 | 20 |  |
| Stone window sill | Window sill peeling | 0.15 | 5 |  |
| Wood window frame | Broken wood window frames | 1.92 | 5 |  |
| Stone railing | Cracked Stone Railing | 1.24 | 5 |  |

**Figure 15.** Building pathology information detailed list (source: author).

This article provides a reference for the causes of historical building pathologies through a systematic pathology list and pathology library. It not only provides a basis for subsequent preventive protection and restoration of historical buildings, but also assists in the safety analysis of historical buildings.

#### 4.3.4. Authenticity-Based Virtual Restoration

The use of virtual simulation technology and digital restoration technology can improve the accuracy and efficiency of historical building protection and repair work. This article first checks the original dimensions of doors, windows, columns, beams, walls, and other components of historical buildings. Then, the current situation of the building is 3D-scanned and modeled. Finally, representative damaged and pathology parts are selected for virtual simulation repair to obtain a repair plan for the building [58].

This article uses the three-dimensional model of historical buildings as an information carrier to establish a virtual repair system to realize the recording, query and statistics of historical building pathology information, and displays the causes, locations, development trends, and other information of historical building pathologies.

Based on data analysis, we conducted an in-depth understanding of the main damaged and pathology parts of historical buildings to provide support for the formulation of repair and protection plans for historical buildings. We selected the most distinctive component of the building—the beam and column system with traditional Chinese characteristics—to construct the "beam and column family (Figure 16a,b)". After analysis, it was found that the surface of the stone beams and pillars was severely weathered due to weathering and solar radiation. We consulted relevant historical data to obtain the size, color and material of beams, columns, and other components; obtained the current status of the components through on-site surveys; and used BIM to restore the components with "authenticity" to provide a visual solution for the later protection and repair of the building (Figure 16c,d). BIM can also be used to collaboratively share repair plans in digital form.

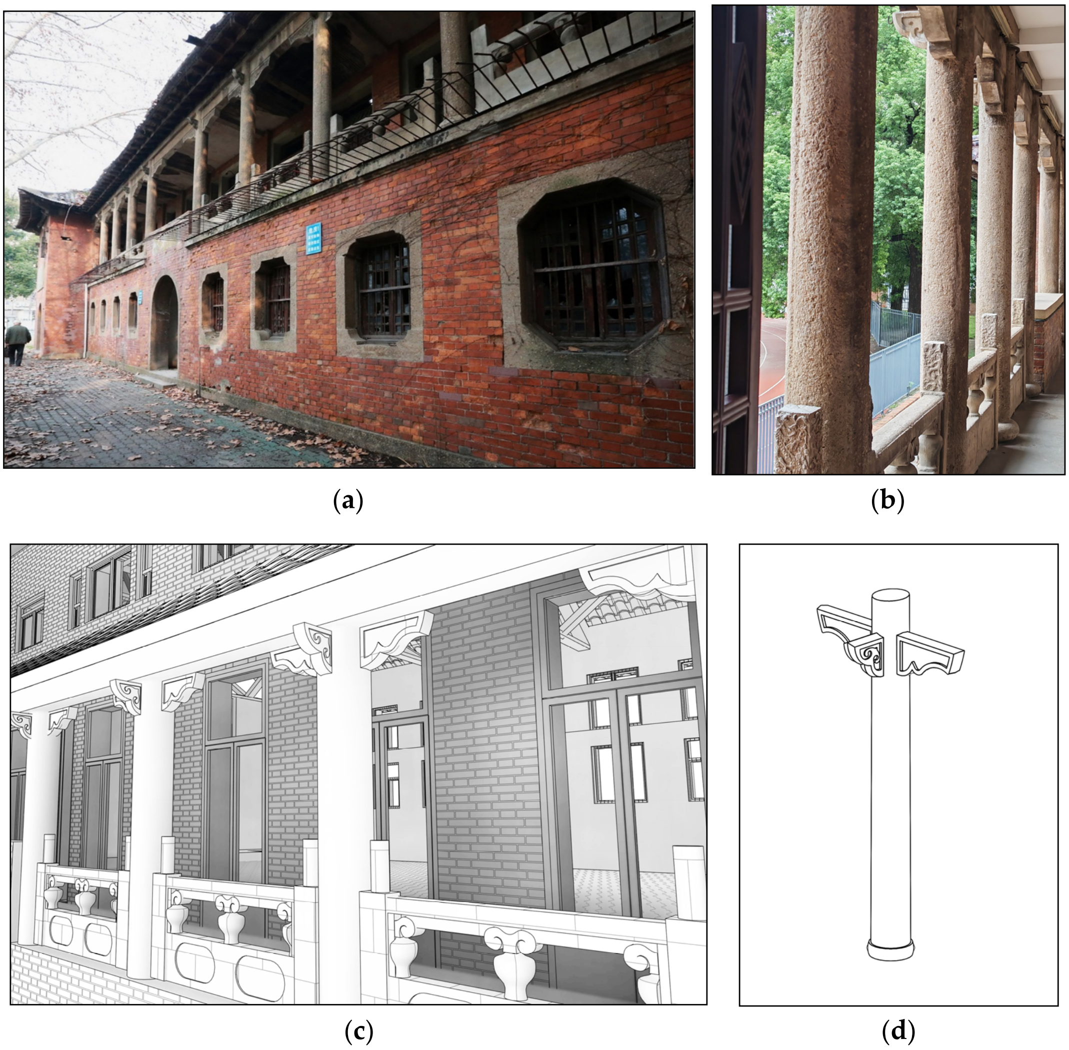



**Figure 16.** Component virtual repair (source: author). (**a**) Second-floor corridor of building. (**b**) Detailed pathologies of column members. (**c**) Virtually restored colonnade. (**d**) Virtually restored column family.

For damaged historical buildings, it is very important to restore the "authenticity" of historical buildings. When it comes to the renovation of historical buildings, designers attach great importance to the "authenticity" of historical buildings to avoid irreversible damage caused by renovations. When carrying out "authenticity" renovations of historical buildings, it is necessary to consider the protection of the surrounding environment of the historical buildings. We can use virtual restoration technology to more intuitively compare multiple restoration plans for historical buildings and restoration measures for the surrounding environment and come up with the best restoration plan.

### *4.4. Pathology Cause Analysis Based on Computer Simulation*

Only by finding out the causes of pathologies and carrying out protection can the resistance of historical buildings to pathologies be improved. The above-mentioned research shows that the causes of James Jackson Gymnasium's pathologies are mainly natural factors such as weathering, moisture, and exposure. Solar radiation, temperature, humidity, etc., are important factors that affect the aging of historical buildings [59]. Therefore, this article uses environmental simulation technology to analyze from the perspectives of sunshine, wind speed, temperature, humidity, etc. It also analyzes the structural deformation and damage of the historical building itself to determine the formation mechanism of the pathology, so as to "prescribe the right medicine" to the historical building and propose appropriate protection and repair plans.

#### 4.4.1. Building Environment Analysis

This article uses Ecotect 2011 building energy consumption analysis software for environmental simulation analysis. The software can interact with BIM models to analyze factors such as solar radiation, enthalpy humidity, and wind direction around historical buildings [60]. This article takes the James Jackson Gymnasium as the research object and inputs its location for environmental simulation analysis.

Through environmental analysis of the Wuchang District of Wuhan City, where the historical buildings are located, we found that the wind frequency in this area is basically lower than 20 km/h (Figure 17a). According to the enthalpy humidity analysis (Figure 17b), the environmental humidity reaches more than 75%. In winter, the temperature is basically above −5 °C, with the lowest temperature from December to February, and the average temperature in July and August can exceed 34 °C [61]. The average solar radiation in the north direction does not exceed 1500 kwh/m$^2$, and the hourly solar radiation throughout the year does not exceed 2500 kwh/m$^2$ (Figure 17c). The distribution pattern is higher in spring and summer and lower in autumn and winter. We observed the changes in building shadows at different periods of the winter solstice in the James Jackson Gymnasium, conducted sunlight analysis on the building, and observed the sunlight time (Figure 17d).

According to the above analysis, the temperature difference between winter and summer in Wuhan is large, which can easily cause cracking or deformation of wood, weathering of stone, and crispness of brick walls. Humidity can cause fungi to grow on wood and mold to grow on wooden components and brick walls.

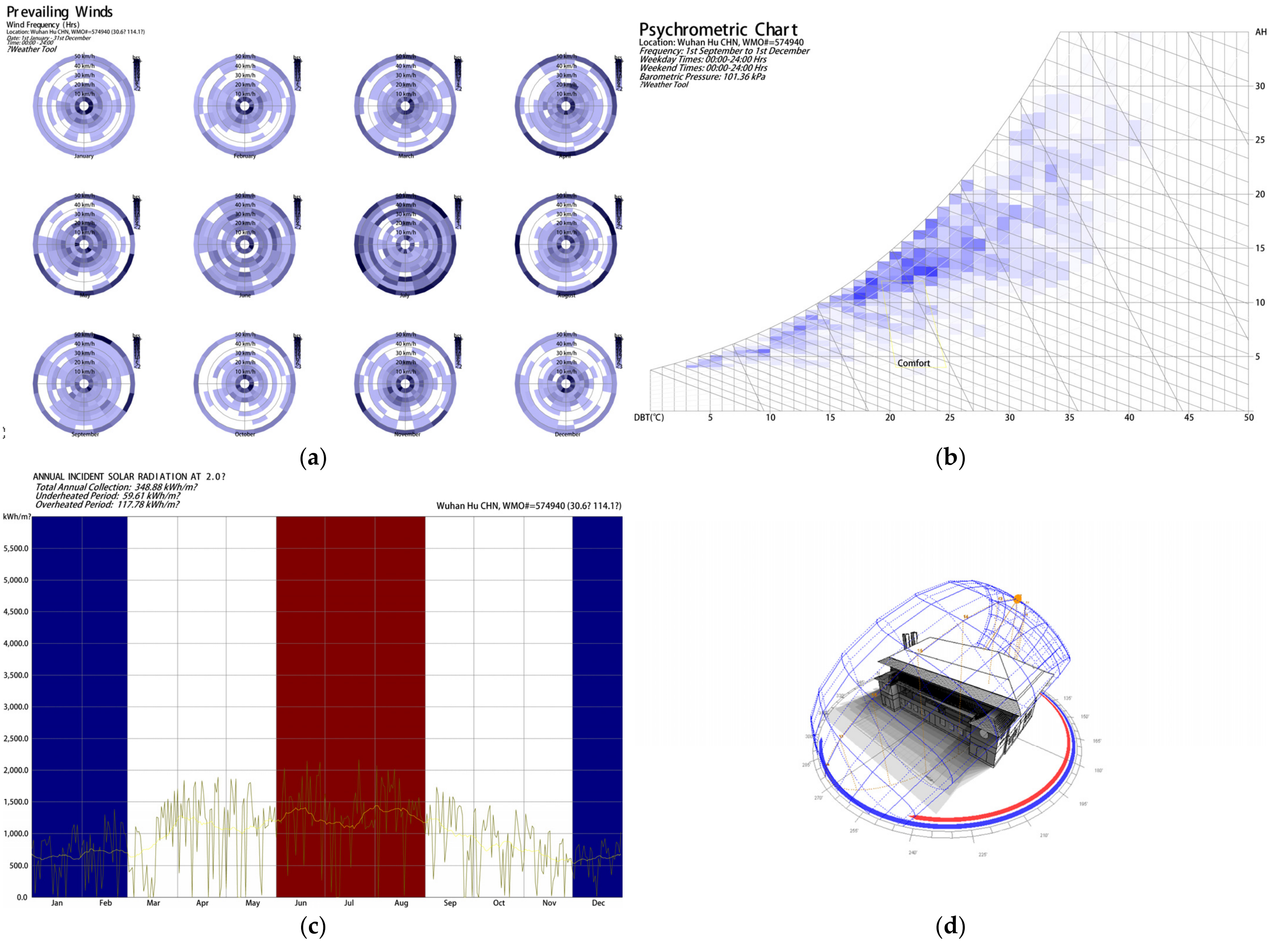



**Figure 17.** Environmental simulation analysis in Wuhan area (source: author). (**a**) Wind environment simulation. (**b**) Enthalpy and humidity analysis. (**c**) Analysis of due-north solar radiation. (**d**) Shadow distribution on the winter solstice.

#### 4.4.2. Building Pathology Damage Detection and Analysis

The structural safety of the historical building itself is the focus of protection and restoration. We conducted comprehensive 3D laser scanning of damp, rotten, cracked, and other parts. A common way to analyze building deformation, damage, and other pathologies is to use point cloud data to generate a rainbow diagram, that is, an elevation deviation analysis diagram. We used Geomagic Qualify 2013 software to compare the differences between two sets of point cloud data of the wall to be detected (the pathology wall) and the wall without pathology, so as to obtain the damage information of the building. The analysis process was as follows:

First, the area of the wall to be inspected at the James Jackson Gymnasium was segmented through point cloud cropping to obtain the point cloud data required for drawing. The trimmed data were then imported into Geomagic, and based on the flat wall data, a wall plane was fitted through the plane-fitting function as the datum plane for flatness measurement. A rainbow map was generated through comparison, the differentiated areas and deviation values were marked, and finally a height-difference comparison map was generated [62]. Compared with manual measurement, this method of comparing point cloud data is more efficient, more accurate, clearer and more intuitive. At present, this method is mainly used to analyze the damage and deformation of walls or masonry pavements.

This article selected the wall on the west side of the building as the analysis object. Through the color difference and texture changes of the elevation deviation analysis map, the damage situation and causes were compared. As shown in Figure 18, in the rainbow diagram of the wall flatness analysis the cool-toned parts are the convex wall parts of the building plane, and the warm-toned parts are the recessed wall parts. The degree of wall deformation can be known based on the color [63]. The elevation deviation analysis results can be used as the basis for later building repairs (Table 4). In addition, through the above research, it can also be inferred that the wall surface is sunken or bulged due to weathering, temperature differences, and other reasons, which once again confirms the architectural pathologies caused by environmental factors [64].

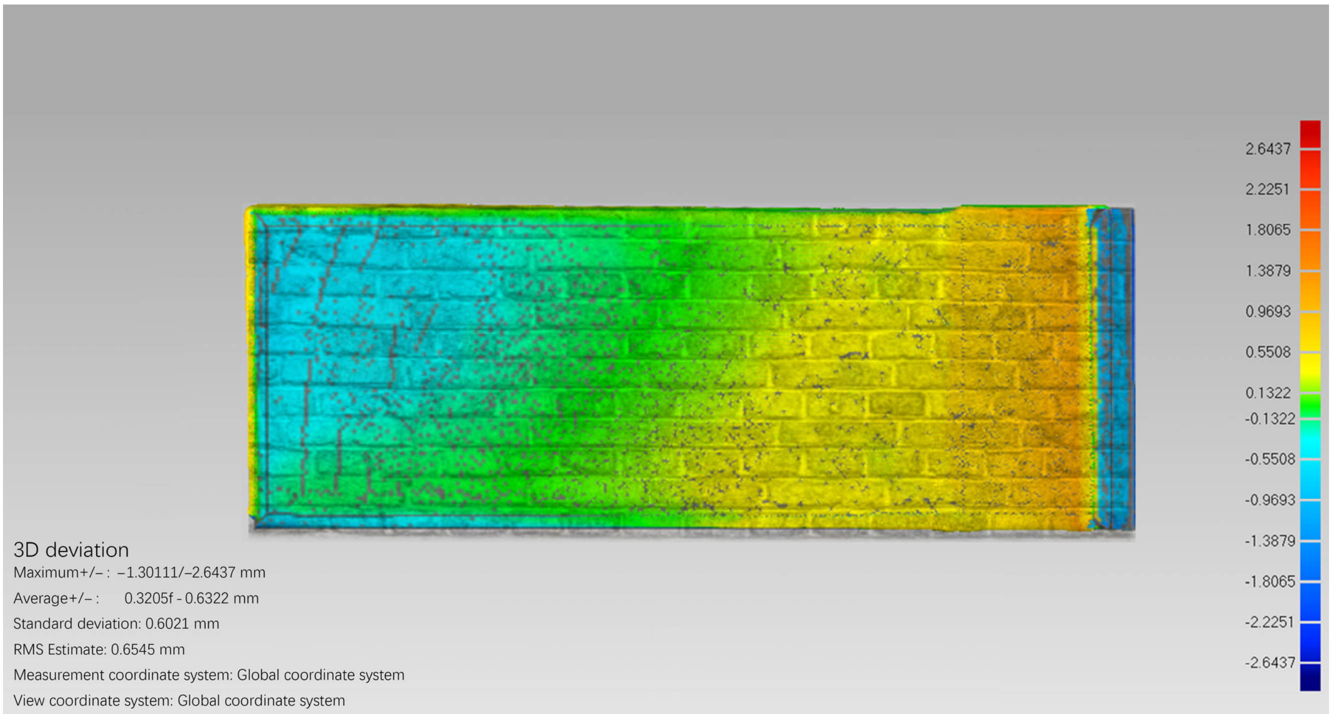



**Figure 18.** Analysis of Building Surface Elevation Deviation (source: author).

**Table 4.** Damage deformation analysis (source: author).

| Project | Describe | Numerical Value/mm |
| --- | --- | --- |
| Damage analysis | Elevation color appears, the overall texture of the wall is greatly different, the flatness on both sides is poor, and there is damage. | Maximum difference 2.005 |
| Deviation analysis | Large deviation within the same wall | |
| Deformation analysis | Both sides of the wall are severely sunken, with a partial protrusion in the middle | |

## 5. Discussion

Based on the above analysis, we concluded the causes of building pathologies and proposed corresponding prevention and control measures.

- Solar radiation: Due to the oxidizing effect of long-wave and short-wave radiation from sunlight, the walls and paintings of historical buildings will crack, become alkali, fall off, fade, and enter other aging states. In the absence of sunlight, some wooden columns, beams, and other wooden components will rot. To address this type of problem, we can use polymer materials or iron components to reinforce the structure, and protect the walls with radiation-resistant materials suitable for painting [65].

- Temperature effect: It is one of the important factors that affect the longevity of historical buildings. Generally, the temperature is around 20 °C. Too high or too low temperatures and changes in temperature differences will cause damage and deformation to the materials of historical buildings. Wuhan belongs to a subtropical monsoon climate zone, with cold winters and hot summers, which are the main factors affecting the deformation and cracking of materials such as wood and tiles.
- Effect of humidity: Its destructive power is manifested in two aspects: increasing the moisture content of wood and breeding fungi. Fungi generally gain moisture from soil or moist materials; the continued increase in moisture can exacerbate the development of pathologies such as mold growth, vesicle formation, peeling paint on walls, and falling mortar. The average precipitation in Wuhan from June to July reaches 210 mm, the relative humidity reaches more than 75%, and the solar radiation is abundant, which provides a suitable environment for plant growth. For example, grass growing on the roof causes the position of the tiles to change and the gaps between the tiles to become larger. Moss or mold will grow on the walls after becoming wet, and wooden components will rot after becoming wet. Therefore, measures such as dehumidification and moisture-proofing are very important. We can use chemical materials or physical instruments for dehumidification, such as activated carbon, calcium oxide, phosphorus pentoxide, dehumidifiers, etc. If conditions permit, infrared thermal imaging cameras can be used to conduct regular inspections of building walls [66].
- Weathering: Most historical buildings have tile roofs. Strong winds will not only blow away or damage the roof tiles, but also blow down buildings with lower strength and weather the building components. For example: stone components are generally located outdoors. When the temperature, humidity, and rainfall are high, the weathering of the stone will be accelerated. In order to prevent stone weathering, silicone coatings and other materials can be added to the surface of the material to prevent stone wind erosion. Stone components can also be repaired using the same material, adhering to the principle of "minimum intervention" for cultural relic restoration, to achieve the effects of removing pathologies, restoring functions, improving the look and feel of stone components, and extending the life of cultural relics [67].

In summary, the critical aspect of protecting and repairing historical buildings lies in the thorough analysis of the underlying causes of pathologies affecting them. Simultaneously, meticulous attention must be devoted to daily monitoring and management efforts to achieve this dual objective. For example: in June and July, when there is a lot of precipitation in Wuhan, humidity and precipitation detection can be increased to conduct real-time dynamic monitoring of the James Jackson Gymnasium and the surrounding geographical environment. Sensors can be set up on building components to interconnect data with the building's three-dimensional information model. When the sensors detect early warning information, they will be reported to the relevant management departments in real time. Based on real-time monitoring data and on-site inspections, the analysis of pathology information and developmental trends is conducted. Additionally, a three-dimensional digital building pathology model is constructed to provide relevant departments with pathology prevention and pathology repair, thereby enhancing the safeguarding of historical buildings and prolonging their longevity.

## 6. Conclusions

This article counts the number of modern educational buildings in Wuhan based on historical research and on-site surveys and selects the James Jackson Gymnasium, the most representative cultural heritage among them, as a typical case to conduct a comprehensive and in-depth study, using three-dimensional scanning technology and BIM technology to obtain, record, and store pathology information to visualize the pathology area, and view the pathology information and development trends of components in an all-round and multi-angle manner. Drawing lessons from the MDDS (Monument Damage Diagnostic System), an international cultural relic and historic site damage diagnosis system, we establish the pathology map management of the BIM model and use virtual simulation technology and digital restoration technology to provide a reference for the daily management, protection and repair of architectural heritage. Finally, environmental simulation technology is used to analyze pathologies induced by natural or human factors, explore the causes of building pathologies, and provide targeted prevention and control measures. The aim is to establish a preventive protection system based on digitalization and achieve sustainable development of historical heritage protection through new technologies.

The use of new technologies and new methods for cultural heritage protection has always been a focus of academic circles. In the future, research can be carried out from the aspects of BIM monitoring, operation, maintenance, management, etc. This article uses a variety of information technologies to analyze from the perspective of pathology, aiming to provide pathology prevention information, extend the life of architectural heritage, and promote the sustainable development of heritage protection and urban renewal, utilizing the sharing characteristics of information technology to enable cultural heritage to transcend the barriers of time and space and assist in the protection of world cultural heritage.

**Author Contributions:** Conceptualization, H.W.; methodology, H.W. and X.H.; software, X.H., S.L. (Siyu Lei), Z.Y. and S.L. (Shengzhong Luo); formal analysis, H.W., X.H. and S.L. (Siyu Lei); investigation, X.H., S.L. (Siyu Lei) and J.L.; writing—original draft preparation, H.W., X.H., S.L. (Siyu Lei) and Z.Y.; writing—review and editing, H.W., X.H. and J.L.; visualization, H.W., X.H., Z.Y., S.L. (Siyu Lei) and S.L. (Shengzhong Luo); supervision, H.W. and Q.Z.; funding acquisition, H.W. All authors have read and agreed to the published version of the manuscript.

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