

**A STUDY OF RETROFIT STRITAGIES ON A
HISTORIC BUILDING IN CHINA TOWARDS
SUSTAINABLE DEVELOPMENT**

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**A STUDY OF RETROFIT STRITAGIES ON A HISTORIC BUILDING IN
CHINA TOWARDS SUSTAINABLE DEVELOPMENT**

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**A project report submitted in partial fulfilment of the
requirements for the award of Master of Sustainable Construction Management**

Faculty of Engineering and Green Technology

Universiti Tunku Abdul Rahman

April 2023

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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I certify that this project report entitled “**A STUDY OF RETROFIT STRITAGIES ON A HISTORIC BUILDING IN CHINA TOWARDS SUSTAINABLE DEVELOPMENT**” was prepared by **YU SHUN YAO** has met the required standard for submission in partial fulfilment of the requirements for the award of Master of Sustainable Construction Management at Universiti Tunku Abdul Rahman.

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ABSTRACT

Over time, historic buildings can be damaged to varying degrees. Therefore, they need to be repaired and retrofitted. However, there are some challenges in this regard. This study uses questionnaire and case study to explore the risks of historic buildings in the renovation process and proposed relevant countermeasures and suggestions. The questionnaire was analyzed using SPSS, including the conservation status of historic buildings, related risks, and people's attitudes towards renovated historic buildings. Three units in the Chinese historic building list were selected for analysis in this study. It mainly discusses the risks in the process of construction and the countermeasures to reduce the risk of destroying the original appearance of the building in the construction process.

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CHAPTER 1

INTRODUCTION

1.1 Background

Historical buildings refer to buildings and structures that have certain protection value, reflect historical features and local characteristics, and are important historical carriers preserved in the process of urban development and evolution.(Ministry of Housing and Urban-Rural Development of PRC,2017)Historic buildings can undergo a series of appraisals and become heritage buildings.The standards and methods for identification shall be formulated by the cultural relics administrative department of the State Council and reported to the State Council for approval. (Cultural Relics Protection Law of PRC,2017)The buildings represent the tangible cultural heritage of a community.(Tan,2016) In China, heritage buildings are classified as immovable cultural relics according to the law, including ancient buildings, important modern historical sites and representative buildings and so on.According to their historical, artistic and scientific value, they can be identified as national key cultural relics protection units, provincial cultural relics protection units, city and county level cultural relics protection units.The heritage buildings involved in this study are all historic buildings.

Strengthening the protection and rational use of the historic buildings is conducive to displaying the historical style of the city and retaining the architectural style and cultural characteristics of the city.

Over time, these buildings can be damaged to varying degrees. Therefore, they need to be repaired and retrofitted. In actual work (such as maintenance, repair and reconstruction of buildings, etc.), historic buildings are different from general buildings. In the process of maintenance and renovation, their superior authorities, legal basis, and construction specifications are also different. The aim is to maintain the quality and functionality of the house and extend its service life. However, there are some challenges in this regard. This paper expounds some problems and risk in the protection and retrofitting of historic buildings, and puts forward relevant suggestions.

For the protection and retrofit strategy of historical buildings, we can divide it into two parts, there are some problems with policy and implementation.

Although many historic buildings are of extremely important cultural and historical value, they have not been fully valued and well preserved for a long time. For a long time, many places have not paid attention to the historical relics that have real protection value, neglected protection or even demolished at will, making way for construction. But at the same time, it will not hesitate to raise huge funds to build an 'ancient town' and an 'ancient city'. Behind this seemingly contradictory behavior, it highlights that in the process of urbanization, many local governments have a serious tendency to operate profit-seeking, overload utilization, and only focus on immediate interests and do not look at long-term development. Creating 'fake antiques' under the guise of developing the cultural tourism industry is self-deception and a great disrespect for historical and cultural heritage.

In this case, there are some historical buildings that have been damaged to

varying degrees, even destroyed. The demolition and reconstruction of the old Jinan Railway Station, also known as Jinan Station of Jinpu Railway, is an extremely painful example. The old Jinan Railway Station was once one of the largest railway stations in East Asia. (Petra Kolonko, 2013) It was designed by the German architect Herman Fisher in the late nineteenth and early twentieth centuries. Although it has unique architectural style, it was not certificated as historic building. In 1992, despite much opposition, the Jinan municipal government demolished the beautiful and meaningful building. Now, people can only see it from the website and from old photos.

Another reality is that many places have taken the wrong approach to the protection of historic buildings. Some cities have built "historical and cultural streets", demolished old buildings, and built some new imitation ancient buildings, such as Furong Street in Jinan and the Confucius Temple in Nanjing. The newly built street does not contain historical information, but also gives people the illusion, which has the bad effect of faking the real thing.(Zhao,2002) It dilutes and affects the preservation of true historical remains. If most people mistakenly believe that antique buildings are the content that a famous historical and cultural city should protect, it is even more wrong.



Figure1.1 The old Jinan train station
(Source:<https://www.163.com/dy/article/DR23OP6U0521C7DD.html>)

From the above case, it can be seen that some local governments do not know enough about the protection policy of the buildings, and even put them in opposition to economic construction, which is wrong. For example, the ancient city of Pingyao was listed as a national historical and cultural city in 1986. The leaders at that time were reluctant to accept this title, suspicious the protection of the ancient city would affect the development of several factories located in the city, and that entering Pingyao would affect the economic development of Pingyao.(Zhao,2002) On the other hand, in the name of protection, some cities use the historical sites of cultural relics and buildings to make money. Lights are used to decorate it for aesthetics and attraction,however, this must ensure the safety of the electrified lines. Otherwise, this is a great safety hazard for many houses, especially flammable wooden buildings.This suggests that the use of historic buildings must take into account the characteristics of the building itself.

In the specific construction process, it is very important not to cause damage

to the building during the repair process, and not to turn a good thing into a bad thing.(Zhao,2002) In a Romanesque church in the northern Spanish town of Estella, a relief statue of “Saint George on Horseback” handed down from the 16th century, because of disrepair, the priest of the church invited a person to restore the statue. Below is a comparison of before and after repairs.



Figure1.2 Comparison of before and after repairs(Source: https://www.sohu.com/a/352408037_99992249)

1.2 Aims, Objectives and Scope of Study

- ① To determine the potential risks in a historical heritage building retrofit project.
- ② To suggest strategies to enhance the feasibility of building retrofitting.

1.3 Research gap

According to the last national census report on immovable cultural relics in 2011, the

results show that the protection status of China's immovable cultural relics is not optimistic, of which 17.77% are in unsatisfactory protection status and 8.43% are in poor preservation status. That is to say, the preservation of about 1/4 of immovable cultural relics (heritage buildings, etc.) is facing major challenges. This reflects the gap in the maintenance and renovation of historic buildings. Relevant studies should be more achievable to guide actual construction.

1.4 Significance of study

The maintenance and retrofitting of historic buildings is different from ordinary construction projects. It does not only aim at the project's own profit, but through providing services for the society, increasing the safety and reliability, energy saving, environmental beautification and other performance of the original project, and then transforming it into social benefits. In other words, it has three meanings: improving the environment, economic benefits, and social benefits.

For such projects that are of a social welfare nature and subject to excessive government intervention, financial evaluation alone cannot truly reflect the economic value of the project output, so it is necessary to evaluate its economic benefits. The benefits of the old house reinforcement project mainly include: the increase in the life value of the house compared to before the reinforcement; the added value of the building area; the difference in benefits brought about by energy-saving renovations; The grade of the city's appearance.

The renovation of buildings has many economic benefits, such as increasing the service life of the house and reducing energy consumption in the long run. This also protects the environment. But the cost of renovating the building and the benefits of renovating it are something to consider.

The renovation cost includes: the seismic identification and reinforcement design cost of the old building, the renovation construction cost (labor cost, machinery cost, material cost, management fee, etc.).Liu(2021)emphasized the importance of control in housing renovation projects, and proposed problems in identification, design, construction, and improvement measures.Yan(2010) uses cost analysis to establish a theoretical model of maintenance costs. But Yan admits that this was influenced by the actual situation during construction.During construction, recycling materials can effectively reduce costs.Building renovation materials are not produced from raw materials, but are upcycled from waste generated during previous demolition.This circular economy not only minimizes demolition waste that ends up in landfills, but also reduces the need for construction raw materials.(Ma,2022)

Regarding the economic benefits of historic building renovation, Qingdao can be used as a success story.The State Guest House, a German castle-style building on Signal Hill, was opened to the public after government renovations.Under the conditions of restrictions, some historic buildings are auctioned, and capable enterprises or individuals can auction old buildings, and then repair and restore them.Founded in 1914, Donglai Bank has experienced different identities such as bank, archive, and insurance company.(Zhang,2011)

CHAPTER 2

LITERATURE REVIEW

2.1 The potential risks in a historic building retrofit project

In response to the risks to historic buildings, Herb Stovel addresses both general and specific aspects of risk preparedness. After presenting the general background and principles, the authors then discuss strategies for targeting various significant risks. These risks include fires, earthquakes, floods, armed conflicts and other disasters.(Herb,1998)

In China, it's slightly different.The risks of renovation projects of historic buildings come from two aspects. On the one hand, the renovation of existing buildings is inherently risky. On the other hand, renovations may destroy the original appearance of a historic building and reduce its value.

Di Xiaotan,an expert from the China Academy of Building Research proposed that there are many risks to be guarded against for the renovation of existing buildings.

- ① Laws, regulations and industry standards are not perfect.

- ② Problems in identification and testing.
- ③ Problems in the construction process.

Di pointed out that the renovation of existing buildings is more difficult than construction projects, coupled with factors such as the relatively small scale of enterprises and imperfect industry supervision, resulting in hidden dangers of safety accidents.(Di,2011)The safety of the structure should be emphasized in terms of testing, design, and construction.

Historic buildings are different from ordinary existing buildings, so when renovating and retrofitting, more issues need to be paid attention to.The risk in this part is mainly the destruction of the historical value of the building. For example, the restoration of Leifeng Pagoda in Hangzhou, China, is still controversial in academic circles.

2.2 Framework and basic process of the renovation project

From 2022, a new mandatory standard, the General Code for the Maintenance and Renovation of Existing Buildings, will be implemented. This new standard is quite different from the previous standard (Standard for Construction of Repairing Civil Building,2019).

In the new standard, a separate section is listed to regulate the inspection of buildings, which was not included in the 2019 version.This is an important addition to the 2019 version and an improvement.For the repair and renovation of buildings, the standard covers from the construction stage to the pre-construction inspection stage.Under this trend, for the repair and renovation of historic buildings, the basic framework is survey and inspection, design, construction (repair), and post-construction maintenance.

2.3 Problems and corresponding countermeasures

In the process of renovation of historic buildings, there are some problems, as well as some countermeasures and solutions.

2.3.1 The policy problem and values

Yangxin(2014) emphasizes the value of historic building maintenance, making the old like old. Only its original appearance, that is, the appearance at the beginning of the construction, can truly explain the historical situation and the level of science and technology at that time. Any modified part that does not follow the original style, whether good or bad, does not account for the situation at that time. This undermines the scientific value of historical buildings as physical illustrations.

With the emphasis on the protection of historical buildings at the social level, government departments have also issued more and more strict regulations. No unit or individual shall damage or arbitrarily relocate or demolish the recognized and announced historical buildings and shall not arbitrarily demolish or damage old buildings with conservation value in the historical and cultural blocks. Under the guise of “necessary infrastructure and public service facilities”, new or expanded projects unrelated to block protection shall not be built or expanded in historical and cultural blocks. Strengthen the safety assessment of historical buildings and carry out salvage repairs on historical buildings with safety risks. Support and encourage giving contemporary functions to historical buildings on the basis of maintaining the appearance and typical components. (Ministry of Housing and Urban-Rural Development of PRC,2021)

Below are some of the policies, laws and regulations that have been enacted regarding the protection and retrofitting of historic buildings:

- Cultural Relics Protection Law of People's Republic of China.(2017).
- Urban and Rural Planning Law of People's Republic of China.(2019).
- Second Amendment to the Construction Act of People's Republic of China.(2019).
- Notice on Strengthening the Protection and Utilization of Historic Buildings.(2017).
- Notice on further strengthening the protection of historical and cultural districts and historic buildings.(2021).
- Standard for construction of repairing civil building. (2019).

It can be seen that for the maintenance and renovation of historic buildings, there are corresponding laws to regulate. In this way, the focus is on specific implementation.

2.3.2 Classic problems and treatment methods in specific construction

There are some specific problems in the project, such as foundation settlement, brick rupture, wood structure decay, etc., there are also corresponding solutions.

2.3.2.1 Foundation settlement and fragmentation

Common damage to the foundations of historic buildings is mainly settlement and fragmentation. The reason is mainly due to the change of the bearing capacity of the

foundation, the influence of groundwater, the growth of tree roots, the damage of underground pipelines, and the damage of external forces. When repairing, it is necessary to first identify the reasons and eliminate these adverse effects. For foundation repair and reinforcement, common methods include compaction grouting and pressed pile by anchor rod. When compaction grouting is adopted, the slurry should be filtered, and the diameter of the solid particles should not exceed 0.1mm. The slurry should have good fluidity, and its diffusion radius should meet the design requirements. The one that needs to be paid attention to when using pressed piles is that pile pressing should be completed at one time. When a stop is required, the tip of the pile should stay in the soft soil layer, and the rest time should not exceed 24 hours. (Ministry of Housing and Urban-Rural Development of PRC, 2019) During the repair process, the original structure and walls must be supported and reinforced, and if necessary, calculations and design plans should be made to ensure safe construction.



Figure 2.1 An example of subsidence asymmetrical of foundation
(Source: <https://www.nuestro.cl/5-facts-you-didnt-know-about-the-leaning-tower-of-pisa/>)

2.3.2.2 Reinforcement of masonry walls

Common reinforcement methods include grouting bonding and reinforcement with metal components.

The common problems are mainly the peeling off and slight breakage of the alkaloid, which are generally caused by weathering, moisture, or external force damage. For the partial peeling or damage of the wall, the surface layer can be removed first to expose the hard part of the bricks. According to the different depths, bricks or bricks can be used to tailor the inlay wall according to the shape of the site and bond it. Firm, after drying, point seam to make it consistent with the whole. If the wall is inclined or cracked, the cause must be found out and eliminated, and a support plan should be formulated at the same time, and then according to the specific situation, either demolish and rebuild or keep it as it is, and fill it with mortar, plain cement slurry or polymer materials dense, and then strengthen the observation.

Dr Kent and Dr Jale pointed out that the existing wood-diaphragm-to-masonry-wall connections in unreinforced masonry (URM) buildings provided very little or insufficient resistance in past earthquakes. (Kent&Jale,2012) Strengthened chord elements, however, are also essential parts of URM buildings to resist earthquakes. And then they propose seismic rehabilitation techniques where steel angles are used as chord reinforcement.

More than 1,000 years ago, waist iron and iron tie rods were used on Zhaozhou Bridge in the Sui Dynasty to enhance its sturdiness. (Luo, 2009) In all parts of southern China, T-shaped iron tie rods are also used to hold the tall brick walls of many dwellings, ancestral halls and temples. Reinforcement with metal components has also achieved remarkable results in the maintenance of ancient buildings in recent decades. For example, in the reinforcement project of the ancient

pagoda, the broken outer wall of the tower body was hooped with steel hoop, and the steel hoop was embedded in the surface of the tower body, and the appearance was still the same.

2.3.2.3 Reinforcement of rotten wooden components

Some ancient buildings are very old, and the wooden components are seriously rotten. It is very complicated and tedious work to restore them to the original state and to meet the dual requirements of aesthetics and cultural relic value. It must be handled carefully according to the location and degree of mildew. For the pillars with serious mildew in the middle and good appearance, we use the heart-filling method to strengthen them. (Huang,2008) First dig out the moldy and rotten things, then process them with new wood according to the size inside, and then put the whole wood into the original moldy part in the middle. The polyester bonding achieves the purpose of the newly added wood to bear the weight, and the appearance retains the vicissitudes of history. Moreover, according to our construction experience over the years, the caliber size of the ancient wooden structure buildings in China according to the principle of mechanical calculation is beyond the coefficient, so this method is very effective.

2.3.2.4 Issues related to building materials

The use of new materials is not to replace the raw materials, but only to reinforce the raw materials and the original structure. (Luo,2009) The application of epoxy resin is a typical example.

The main hall of Baoguo Temple in Ningbo, Zhejiang Province has a history

of more than 1,000 years. It is one of the few early wooden buildings in existence. Most of the pillars of the main hall have been eaten by termites. There are three ways to do repairs. The first method is to replace it directly with cement. However, the blind use of cement will make the building lose its original style, thereby reducing its historical and aesthetic value. The second is to replace it with new wood. Although this method preserves the wooden structure, the 900-year-old experience of the previous columns is lost, and the original wood is not easy to find. Therefore, the third method is adopted, that is, to solve it with new materials and new technologies. It is filled with epoxy resin formulations, which not only preserves the main components of the hall for more than 90 years, but also solves the problem of reinforcement of the columns. Luo Zhewen believes that this is a good example in the maintenance of ancient buildings. Epoxy resin formulations can also be used for bonding wood, inlaying some incomplete and decaying parts of the original components, masonry buildings, bonding and reinforcement of grotto cliff walls, and filling.

2.3.3 The application of new technologies

2.3.3.1 Three-dimensional laser scanning measurement

The traditional 3D data acquisition methods mainly include the method of single-point acquisition of 3D coordinates, close-range photogrammetry, aerial photogrammetry, etc. The former such as GPS high-precision positioning, 3D coordinate measuring machine, total station system, etc. There is a big difference between 3D laser scanning technology and traditional technical means. This technology breaks through the traditional single-point measurement method and can quickly obtain massive 3D coordinate data on the surface of objects. These 3D coordinate data are also called point clouds. The whole process of 3D laser scanning measurement mainly includes three steps: site survey and fixed point,

implementation scanning, point cloud data processing and modeling (as shown in the figure). Each step has its own implementation requirements or detailed process.

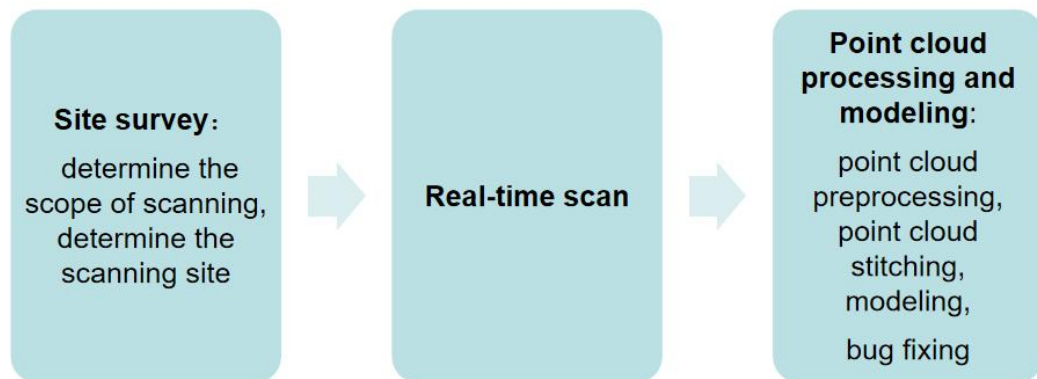


Figure 2.2: The process of using laser scanning

In the 2008 Wenchuan earthquake, many historical sites such as Dujiang Dam and Erwang Temple in Sichuan Province were damaged to varying degrees. During the post-disaster maintenance process, the cultural relics protection workers encountered the lack of detailed structural drawings of the original buildings and the difficulty of damage. Problems such as calculation, difficult measurement and replacement of damaged parts. In the following three years, Chinese cultural relics protection workers have increasingly applied 3D laser measurement technology to the restoration of historical buildings.

2.3.3.2 Virtual reality technology (VR)

Virtual reality technology is a computer simulation system that can create and experience virtual worlds. It uses computers to generate a simulation environment. People bring an immersive feeling, and this technology is gradually permeating all aspects of social life. Lü points out that the emergence of virtual reality technology

provides greater possibilities for the restoration of historical buildings, and it has important application advantages in this regard. In the baptism of wind and frost in the long history, historical buildings are often incomplete, the building components tend to be aging, and the building exterior has been remodeled to varying degrees. The application of virtual reality technology can restore the original appearance of historical buildings on the basis of existing technology, and even for building components that have been demolished, the use of virtual reality technology can also be used to recreate, simulating the real environment of historical buildings to the greatest extent. And the construction work can be guided accordingly. (Lü,2019)

The historical building maintenance project involves a large number of construction links, and there is a close connection between the maintenance and construction links. Once one of the links goes wrong, the overall construction quality and construction progress will be affected. Relying on virtual reality technology, maintenance personnel can make pre-planning arrangements in a more comprehensive grasp of the maintenance construction site, surrounding scenes, mechanical equipment and structural components, and form a virtual construction environment with dynamic performance to predict the feasibility of engineering construction and accident prediction. and production scheduling optimization and other aspects of analysis and forecasting. And it can track every link of the maintenance and construction process, conduct experiments on the whole process of construction and production, and conduct construction simulation before the construction starts, input engineering data into the computer system, evaluate the data intelligently, and formulate the optimal construction plan.

The maintenance of historical buildings based on virtual reality technology can greatly improve the efficiency of project management and construction by establishing a virtual model and a virtual construction process, ensure the progress of the schedule, save costs, improve safety, and reduce maintenance engineering risks. With the further development of technology, the application of virtual technology in

the maintenance process of historical buildings has broad prospects.

2.4 Historic buildings retrofitting towards sustainable development

Retrofitting historic buildings can be a challenge, as their original construction and design may not be suited to modern systems. However, it is possible to retrofit historic buildings with sustainable design principles while still preserving their historic character. Preserving the historic character of the building is also an important part of retrofitting for sustainable development. Original materials and architectural features can be carefully restored and repaired, and new additions or modifications can be designed to complement the historic building. The United Nations Department of Economic and Social Affairs has identified 17 Sustainable Development Goals (SDGs). Goal 11 is "Make cities and human settlements inclusive, safe, resilient and sustainable", which specifically requires strengthening and protecting cultural heritage. (UN Department of Economic and Social Affairs, 2023) In other words, the maintenance and retrofitting of historic buildings, especially heritage buildings, is itself beneficial for sustainable development.

The identification and protection of historical buildings need to be further strengthened. When restoring and retrofitting a historic building, 'secondary damage' to the building should be avoided. The original appearance of the building should be restored as much as possible.

After establishing the goal of protection, people will face some technical problems in the specific implementation. People should preserve the building structure, building materials and arts and crafts. (Luo, 2009) Therefore, caution must be exercised in the use of modern materials such as cement.

As an important part of excellent traditional culture, historical buildings should be revitalized and charming in the protection and utilization. However, some historical buildings have gradually disappeared with the boom in urban construction, and some of them have been rebuilt, but they have been replaced by batches of "fake antiques" without historical information. Therefore, the Ministry of Housing and Urban-Rural Development proposed that all localities should strengthen the strict protection of historical buildings, and strictly prohibit the random demolition and destruction of old houses, modern buildings and industrial heritage that have been identified as historical buildings.(Ministry of Housing and Urban-Rural Development of PRC,2017)

The maintenance and retrofitting of historical buildings should fully consider the coordination with the surrounding historical features in terms of building materials, architectural colors, architectural styles and so on, which greatly increases the difficulty of maintenance. In order to solve these problems, corresponding technical means need to be used.

CHAPTER 3

RESEARCH METHODOLOGY AND WORK PLAN

3.1 Introduction and Research Design

The research adopts a combination of qualitative and quantitative research methods, including questionnaires, and case study (field investigations). This is mainly the collection and analysis of cases and information.

This study adopts the form of questionnaire to investigate the attitude of relevant practitioners. In addition, in order to make the research more specific and give suggestions for the actual project, the analysis of the actual project is important. Therefore, an on-site investigation is necessary. Photos, videos, etc. of the on-site investigation can also enrich the details of the investigation.

3.2 Information and Data Collection

The questionnaire was conducted online. Since the respondents were in China, the study used Chinese questionnaire software, which functions similarly to Google Form. The following are the URLs, account numbers and passwords of the questionnaires involved in this study:

Link:<<https://www.wjx.cn/>>

● Questions in the questionnaire:

(1)Gender

(2)Geographic region

(3)Working position

Design Construction Supervision Developer

Relevant competent department Others

(4) Working Experience

Less than 1 year 1 - 2 years

3 - 5 years More than 5 Years

(5) Is your city listed as a state-list famous historical and cultural cities?

Yes No

(6)Are there any heritage buildings or historic buildings in your place of residence or domicile? Yes No

(7)How well heritage buildings or historic buildings are preserved, based on what you have seen or known through other means.

Very good Good Acceptable Poor

(8)In your opinion, a historic or heritage building is well protected because it looks like:

No visible damage

No rain leakage

Historical features have been preserved

Clean and tidy, like a new building

(9) In your opinion, a historic or heritage building is not well protected because it looks like:

- Lack of cleanup, overgrown with weeds
- Lost its historical character
- Commercialization is too serious
- Obvious damage or structural safety issues

(10) What do you think are the deficiencies in the protection of heritage buildings (if any)?

- The building lacked protection and fell into disrepair
- The heritage buildings are not in harmony with the surrounding environment
- Tourism is overdeveloped and the commercial atmosphere is too strong
- Damage was caused during the protection process of the building

(11) Have you heard of the *Cultural Relics Protection Law*?

- Yes No

(12) In your opinion, what are the main risks in the maintenance and retrofitting of cultural relics buildings?

Options	Completely disagree	Disagree	General	Agree	Strongly agree
Unauthorized alteration by building managers, change of building use, etc					
Unsafe use of electricity					
Relevant laws and norms need to be improved					
The qualifications of relevant units are not up to standard					
The inspection of the building is wrong					
Limited materials and technology					
Blind construction					

(13) The maintenance of heritage buildings is necessarily time and money-consuming. How do you evaluate the financial expenditure and tourism inconvenience caused by this?

Under the premise of ensuring that the purpose is achieved (the ancient buildings are indeed properly protected), it is understandable that these situations occur.

Before protecting a building, the government department should make a detailed assessment of such situations, give a conservation plan, and obtain the consent of the local people.

This is not necessarily a bad consequence, because until protection programmes are mature, there is a need to be tolerant of situations such as fiscal deficits.

If the cost is too high, maintenance is not necessary

(14) What attitude do you think should be taken towards the restoration of heritage buildings?

Leave it as it is, nothing has changed

On the basis of the original, modern technology can be used appropriately

Use the original process whenever possible

Build a new one

● Objects of site investigation (buildings), selection criteria:

(1) It can reflect the history and culture of a period or the life of the people at that time. The historic building is on the relevant conservation list.

(2) There is no serious risk of collapse (safety).

(3) It is not in ruins (repair and renovation is possible).

(4) It is better to have some aesthetic value.

● Highlights of on-site surveys:

(1) Basic information about the building: structural form, use, age, etc.

(2) The details of the building: the use of building materials, interior decoration, etc.

(3) The severity of building damage: foundation subsidence, whether the load-bearing structure is damaged, whether it leaks rain, etc.

(4) Whether the building has been repaired and retrofitted and how it is carried out.

(5) If it is repaired, how effective it is, and whether it has achieved its purpose.

(6) What are the risks that distinguish this historic building from traditional building projects in a repair and renovation project?

(7) How did the project team respond to the risk, and what strategies and suggestions are available?

Based on the above criteria, three sites were selected for this study: Hongjialou Cathedral, Four Gates Pagoda, and Temple and Cemetery of Confucius and the Kong Family Mansion in Qufu. Further details and the investigation report are annexed. Since the receiving investigator was unwilling to provide personal information, the survey report was included in the appendix. Here's basic information about these three sites.

Table 3.1: Basic information of Four Gates Pagoda

Name	Four Gates Pagoda
Location	Licheng District, Jinan City, Shandong Province, China
Completion time	AD 611, Sui Dynasty
Architectural style	One-storey, pavilion-style pagodas
Structural form	Square single-storey pavilion-style stone pagoda with a height of 15.04 meters. All elements of the structure are symmetrical with four identical sides each facing one of the four cardinal directions (East, West, South, North).
Building material	The material is stone bricks, quarried in the local mountains and belongs to limestone.
The original purpose of the building	Religion, Buddhism
The value of the building	
Protected list: The pagoda has been listed as a Major Historical and Cultural Site Protected at the National Level since 1961.	
The main current use of the building: Tourist attractions	
Social benefits and others: The Four Gates Pagoda is the only surviving Sui Dynasty stone pagoda in China, and it is also the earliest and most complete surviving single-storey pavilion-style stupa in China.	

Table 3.2: Basic information of Hongjialou Cathedral

Name	Hongjialou Cathedral
Location	Licheng District, Jinan City, Shandong Province, China
Completion time	1905
Architectural style	Gothic Revival
Building material	The material is stone bricks, quarried in Jinan and belongs to limestone.
The original purpose of the building	Places of Christian activity
The value of the building	
Protected list: In 2009, it was announced by the State Council as a national key cultural relic protection unit.	
The main current use of the building: 1. Tourist attractions 2. Places of Christian activity	
Social benefits and others: Well-known attractions in Jinan; The largest Catholic church in North China	

Table 3.3: Basic information of the Temple and Cemetery of Confucius and the Kong Family Mansion

Name	Temple and Cemetery of Confucius and the Kong Family Mansion
Location	Qufu City, Shandong Province, China
Completion time	478BC----the earliest recorded More details are provided in report.
Building material	Wood, masonry
The original purpose of the building	Residences, sacrifices, tombs
The value of the building	
Protected list: State Priority Protected Sites in 1961; United Nations Educational, Scientific, and Cultural Organization (UNESCO), World Heritage List (https://whc.unesco.org/en/list/704/)	
The main current use of the building: Tourist attractions	
Social benefits and others: A representative of oriental architectural techniques, and has a deep historical connotation.	



Figure 3.1 : Four Gates Pagoda



Figure3.2: Hongjialou Cathedral



Figure3.3: Temple and Cemetery of Confucius and the Kong Family Mansion
(Source:http://k.sina.com.cn/article_7042248789_p1a3c0305500100k1ot.html#/)

3.3 Sampling Design

The questionnaire survey adopts the method of sampling survey to investigate the attitude of relevant practitioners towards the protection of historic buildings, the current status of building protection, and related risks. Non-probability sampling method is selected-purposive (judgmental) sampling. The questionnaire covered seven regions in China, and surveyed employees in the construction industry and competent departments.

3.4 Information Analysis Techniques

Questionnaire data analysis was performed using SPSS. It is the abbreviation of Statistical Product and Service Solutions, which is a general term for IBM's software products and related services for statistical analysis operations, data mining, predictive analysis and decision support tasks. It provides a user-friendly interface and a powerful set of features that allow organizations to quickly extract actionable insights from data.

For the actual project, qualitative research is used to analyze the characteristics of the project, what risks there are, how to deal with it, and what construction technology is used from the specific building restoration and retrofitting.

CHAPTER 4

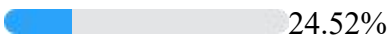
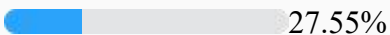
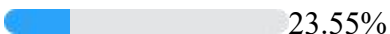
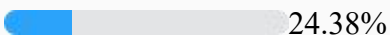
RESULTS AND DISCUSSIONS

4.1 Analysis of the conservation of historic buildings

In order to determine the risk of renovation of historic buildings, questionnaires, interviews, and surveys of specific historic buildings were used.

Before identifying these risk factors, it is necessary to collate and analyze the current status of historic buildings. One thousand questionnaires were sent and 726 completed questionnaires were returned. The 726 questionnaires surveyed the protection of cultural historic buildings in seven administrative regions of China, as follows:

Table4.1: Questionnaire statistics on the preservation of historic buildings in China

Options	Number of people	Proportions
Very good	178	 24.52%
Good	200	 27.55%
Acceptable	171	 23.55%
Unacceptable/Poor	177	 24.38%
The number of people to fill in this question	726	

As can be seen from the above table, 24.38% of the historic buildings are not well protected. This ratio is basically in line with the 26.2% of the results of the last census of immovable cultural relics in China. Of course, due to the difference in sample size , survey time and survey methods, this is inevitable to have certain differences. There are certain differences in the protection of cultural relics buildings in different regions. From the following cross-analysis table, it can be seen that the conservation of historic buildings in South and Central China faces greater challenges than other regions.

Table4.2:Cross-analysis table of statistics on the conservation of historic buildings and regions

X\Y	Very good	Good	Acceptable	Poor	Number
East China	26.44%	27.59%	26.44%	19.54%	87
North China	23.48%	33.91%	24.35%	18.26%	115
Northeast China	24%	33%	19%	24%	100
Northwest China	20.59%	25.49%	30.39%	23.53%	102
Southwest China	27.55%	27.55%	25.51%	19.39%	98
South China	25.44%	21.93%	21.05%	31.58%	114
Central China	24.55%	23.64%	19.09%	32.73%	110

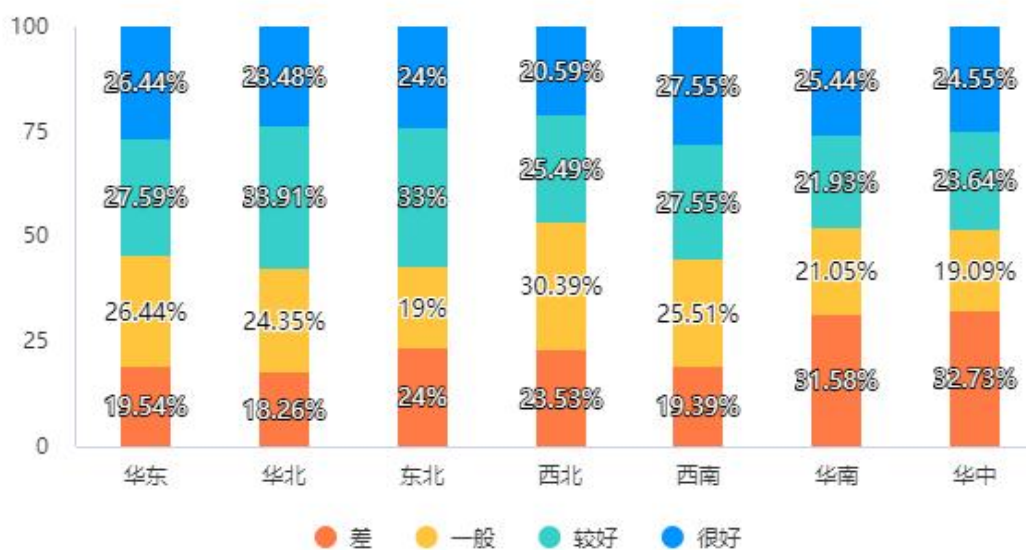


Figure4.1:Cross-analysis bar chart of statistics on the conservation of historic buildings and regions

In the questionnaire, relevant data were collected to analyze the current state of historic buildings and the views of practitioners. By the SPSS software, 726 samples were taken from the questionnaire for analysis, and the results were as follows:

Table 4.3: Chi-Square Analysis of statistics on the different views of what constitutes a well-preserved historic building

Chi-Square Analysis							
Categories	Occupation: (%)						Total (<i>n</i> =726)
	Design (<i>n</i> =122)	Construction (<i>n</i> =120)	Supervision (<i>n</i> =122)	Developer (<i>n</i> =119)	Competent authorities (<i>n</i> =112)	Others (<i>n</i> =131)	
Clean and tidy, like a new building	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
No visible damage	78 (63.93)	80 (66.67)	77 (63.11)	86 (72.27)	71 (63.39)	81 (61.83)	473 (65.15)
No rain leakage	76 (62.30)	72 (60.00)	65 (53.28)	68 (57.14)	76 (67.86)	81 (61.83)	438 (60.33)
Historical features are well preserved	78 (63.93)	75 (62.50)	82 (67.21)	65 (54.62)	76 (67.86)	95 (72.52)	471 (64.88)
Chi-Square Test:	No visible damage				$\chi^2=3.867$	$p=0.569$	
	No rain leakage				$\chi^2=6.017$	$p=0.305$	
	Historical features are well preserved				$\chi^2=9.923$	$p=0.077$	

This Chi-Square analysis table is used to analyse the perceptions of different occupations on historic building maintenance. The question is about the perception of different occupations on the effects of restoration of historic buildings with suitability. The interesting aspect is that despite the occupations, there was no clear difference in the attitudes of the respondents. At the same time, the results of the survey show that the respondents showed a consistent view on this issue: a well-restored historic building should prevent damage, prevent leakage, and maintain its historical character, not make it look new. The reason for this result may be the popularization of the concept of cultural heritage protection, which has given people a basic understanding of the restoration of historic buildings.

4.2 Analysis of the risk for historic buildings retrofitting project--based on questionnaires and field surveys

In the 726 questionnaires, the relevant personnel considered that there are many risks in the repair and retrofitting of historic buildings, which are summarized as follows:

- Unauthorized alteration by building managers, change of building use, etc
- Unsafe use of electricity
- Relevant laws and norms need to be improved
- The qualifications of relevant units are not up to standard
- The inspection of the building is wrong
- Limited materials and technology
- Blind construction

In the questionnaire, the attitude of the respondents to the above risks are summarized in the Table4.4. The table shows the four attitudes of the respondents: completely disagree,disagree,general,agree and strongly agree . This will analyze the possible risk factors for the retrofitting and renovation of historic buildings.

Table 4.4: The risks to be aware of in the maintenance and retrofitting of historic buildings

Options	Completely disagree	Disagree	General	Agree	Strongly agree
Unauthorized alteration by building managers, change of building use, etc	0(0%)	1(0.14%)	373(51.38%)	352(48.48%)	0(0%)
Unsafe use of electricity	0(0%)	1(0.14%)	381(52.48%)	344(47.38%)	0(0%)
Relevant laws and norms need to be improved	0(0%)	0(0%)	372(51.24%)	354(48.76%)	0(0%)
The qualifications of relevant units are not up to standard	0(0%)	0(0%)	369(50.83%)	357(49.17%)	0(0%)
The inspection of the building is wrong	0(0%)	0(0%)	362(49.86%)	364(50.14%)	0(0%)
Limited materials and technology	0(0%)	0(0%)	349(48.07%)	377(51.93%)	0(0%)
Blind construction	0(0%)	0(0%)	394(54.27%)	332(45.73%)	0(0%)

The study surveyed three heritage buildings (sites):

Four Gates Pagoda, a national cultural relic protection unit in China;

Hongjialou Cathedral, a national cultural relic protection unit in China;

Temple and Cemetery of Confucius and the Kong Family Mansion, United Nations Educational, Scientific, and Cultural Organization (UNESCO), World Heritage List (<https://whc.unesco.org/en/list/704/>)

In view of the risks of historic building repair and renovation projects, interviews and field survey results are summarized below:

Table 4.5: Summary of risk issues in project by surveys

Survey method	Projects involved	Project risks and difficulties in the process
Field investigations	Renovation of the Four Gates Pagoda	Security of antiques in historic buildings; Antiques in the pagoda were stolen in 1997.(manager)
	Renovation of the Four Gates Pagoda,1951	Buildings are at risk of collapse;(manager)
	Renovation of the Four Gates Pagoda	Damage to the original appearance of the building(manager)
	Renovation of the Hongjialou Cathedral	Damage to the original appearance of the building(manager)
	Reconstruction project of the statue of Dacheng Hall of Confucius Temple	The rebuilt appearance is inconsistent with the original(manager)
	Confucius Temple Kuiwen Pavilion repair project	Damage to original components and decorations(maintenance workers)
	Restoration of ancient buildings inside the Kong Family Mansion	Damage to the original appearance of the buildings(maintenance workers)
	Confucius Temple & Kong Family Mansion	Fire risk in timber structure buildings(manager)

From the results of Table 4.4, the risks of restoration and retrofitting of historic buildings are as follows:

- ①Unauthorized alteration by building managers, change of building use, etc
- ②Unsafe use of electricity
- ③Relevant laws and norms need to be improved
- ④The qualifications of relevant units are not up to standard
- ⑤The inspection of the building is wrong

- ⑥ Limited materials and technology
- ⑦ Blind construction
- ⑧ Extreme weather such as lightning strikes

Further generalizations can be made from the above 8 articles. Lightning strikes and unsafe electrification can easily lead to fires, especially since many historic buildings are timber. False detection, blind construction, limited material technology, etc., can all be attributed to problems that arise during the project. Enterprise qualifications, construction specifications and other issues are related to industry standards.

From the results of Table 4.5, the main risk in the project was the destruction of the historic building itself during the repair process, thereby destroying the original appearance of the building. In addition, it should be noted that due to the special nature of historic buildings, they will receive help from relevant government departments in the restoration and protection. (Cultural Relics Protection Law of PRC, 2017) As a result, there will be less risk in terms of construction schedule and cost. At the same time, the requirements for engineering quality are strict. This is to ensure the restoration of historic buildings.

4.3 Survey overview of the buildings

Basic information on these three locations is provided in chapter III. It can be seen that although the use of the building is not entirely consistent with the use when it was originally built. These historic buildings still play a role. These three sites currently mainly serve as tourist attractions and become landmarks of the

community.(manager)It is precisely because of the importance of these buildings that the renovation process has been valued and carried out in a cautious manner.

Since these historical buildings are not used for living, their renovation and retrofitting are mainly for the repair of damaged parts, not involving gas, indoor lighting, etc. In this study, the renovation involved in the main structure reinforcement work, roof waterproof work, floor work, decoration work and so on.In these work, a large number of natural materials and traditional crafts, played a role in protecting the environment, but also maintain the original appearance and historical characteristics of the building, so as to maintain the community style. In this way, these buildings attract tourists as attractions, and increase the social and economic benefits.In conclusion, this is beneficial for sustainable development.

4.4 Strategies and countermeasures

4.4.1 Combining traditional craftsmanship with modern technology

The survey of historic buildings shows that the project team used modern technology and traditional craftsmanship in the restoration process to achieve the restoration effect of maintaining the appearance of the building without damaging its historical value.Anonymous project personnel or managers are represented by job titles.

Table 4.6: Some traditional craftsmanship in process

Work	Process & Technology	Corresponding heritage buildings
Laying floor tiles	Dipping bricks with raw tung-oil;(labour) Apply tung-oil to the surface of the floor tiles.(labour)	Temple and Cemetery of Confucius and the Kong Family Mansion
Paste paper	Use flour and water to stir into a paste as a binder, and add additives such as spices.(manager)	Temple and Cemetery of Confucius and the Kong Family Mansion
Roof waterproofing 1	Waterproof layer: stone tile; Lime mixed with loess in a ratio of 3: 7; "Tin back" waterproof layer, is a lead-tin alloy sheet.(manager)	Four Gates Pagoda
Roof waterproofing 2	"Grey back" waterproofing: It is made of lime,chop the hemp rope (plant fiber), green ash (graphite containing impurities) and other materials mixed into a slurry. It is used in a manner similar to modern cement mortar, which is applied to the joints,nodes and layer of the roof and cured to form a hard waterproof coating.(manager) Install roofing tiles(maintenance workers)	Hongjialou Cathedral; Temple and Cemetery of Confucius and the Kong Family Mansion
Woodwork	Use mortise and tenon to connect components(labour)	Temple and Cemetery of Confucius and the Kong Family Mansion

The three historic buildings (sites) surveyed had one thing in common during the repair process. All have roofing works and are restored using traditional techniques.

Below is a diagram of a traditional Chinese roofing project.

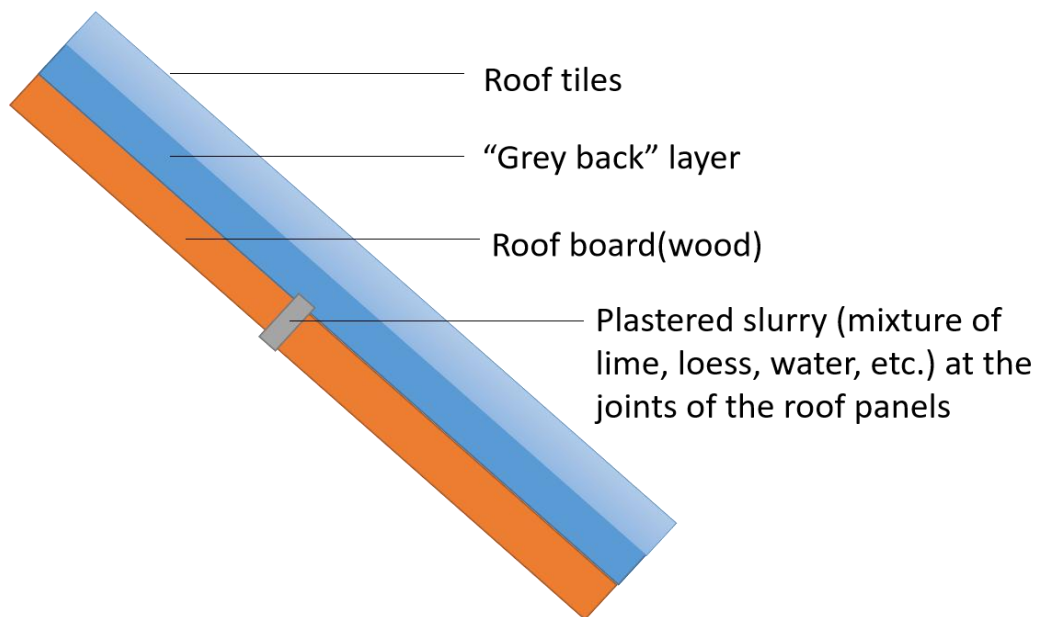


Figure4.2 :A traditional roofing practice (including waterproofing),gray back



Figure4.3: One of the raw materials of slurry, plant fiber
(Source:<https://www.17yike.com/index.php/home/index/quan/id/597687379168.html>)



Figure4.4:Plastering at the joints of the roof panels
(Source:http://society.sohu.com/a/576510128_121106842)



Figure4.5:The fibers are mixed with the slurry, compacted, and dried
(Source:https://www.bilibili.com/video/av502740649/?vd_source=d10cec5bb9d10ac220b34f0aca2add2c)



Figure 4.6: Install roofing tiles

(Source:https://www.bilibili.com/video/BV1NK411c76x/?spm_id_from=333.788.recommend_more_video.-1&vd_source=d10cec5bb9d10ac220b34f0aca2add2c)

Table 4.7: Some modern technology in project

Work	Process & Technology	Corresponding heritage buildings
Pre-construction inspection	3D scanning(manager)	Four Gates Pagoda
Reinforcement and restoration of timber structures	Fill cracks with epoxy resin; Reinforcement with rebar; Wood preservative(manager)	Temple and Cemetery of Confucius and the Kong Family Mansion
Reinforcement of the tower body of the stone tower	Iron hoop reinforcement (manager)	Four Gates Pagoda

Thus, in concrete projects, traditional craftsmanship and modern technology are used appropriately to ensure the proper restoration and retrofitting of historic buildings.

4.3.2 Relevant standards are introduced and complied with

In order to implement the laws and regulations on the protection of cultural relics and effectively protect historical buildings and heritage buildings, the relevant departments in China have formulated a series of standards and norms, and have continuously improved and updated.

These industry standards cover many aspects of historic building renovation and

some are listed below:

- The code of construction supervision for ancient architecture conservation projects,2012;
- Technical specifications for lightning protection engineering of ancient buildings,2014;
- Technical standards for the maintenance and reinforcement of wooden structures of ancient buildings,2014;
- Guideline for structural safety assessment of modern historic building,2014;
- Specification for digitalized surveying and mapping of wall painting in historic building,2017.

In addition, the State Administration of Cultural Heritage has regulated the materials used in construction and classified them under the industry standard for the protection of cultural relics. Here are some regulations related to building materials:

- Material for maintenance and conservation of historic architecture -- Grey brick,2014
- Material for maintenance and conservation of historic architecture -- Grey tile,2014
- Material for maintenance and conservation of historic architecture -- Timber,2014
- Material for maintenance and conservation of historic architecture -- Stone,2014

As industry standards continue to evolve and apply, renovation projects for heritage buildings can be better monitored.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

The protection of historic buildings, especially heritage buildings, plays an important role in the sustainable development of cities and communities. This can reflect the environmental, economic and social benefits. Over time, historic buildings can be damaged to varying degrees. Therefore, they need to be repaired and retrofitted.

- For objective①: To determine the potential risks in a historical heritage building retrofit project.

For such projects, there are many risks compared to traditional construction projects, such as inadequate inspection of historic buildings, blind construction, limited materials and processes, and so on. This is manifested in the destruction of the historical value of the historic building, and the failure to restore and renovate the building according to its original appearance.

- For objective②: To suggest strategies to enhance the feasibility of building retrofitting.

In response to such problems, this study makes the following suggestions:

According to the questionnaire, the vast majority of respondents requested that the original features of the historic building be preserved when restoring. Instead

of building a new one.(Table5.2)Before starting construction, rational use of modern technology, such as 3D scanning, to conduct surveys and restore the original appearance of the building.During the construction process, traditional craftsmanship is used for the exterior part of the building, such as roofing and painting, to ensure the restoration effect of the exterior(In Table5.1). For the load-bearing structure of the building, traditional technology is combined with modern technology to ensure the structural safety of the building.


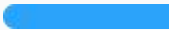


- Recommendations

This study proposes some recommendations about retrofitting historical heritage buildings.Due to its unique historical and cultural value, it should be well protected. Therefore, it is necessary to identify possible risks during the project so that their historical value is not damaged, especially during the construction process.Among them, traditional materials and technology should be valued, because many traditional building materials are pollution-free natural materials, such as hemp and loess, and some materials are cheap, taking into account the environmental and economic benefits.In addition ,it maintain the original appearance and historical characteristics of the building, so as to maintain the community style and increase the social benefit. In conclusion, this is beneficial for sustainable development.

Table 5.1: Some traditional craftsmanship in process

Work	Process & Technology	Corresponding historic buildings
Laying floor tiles	Dipping bricks with raw tung-oil; Apply tung-oil to the surface of the floor tiles.	Temple and Cemetery of Confucius and the Kong Family Mansion
Paste paper	Use flour and water to stir into a paste as a binder, and add additives such as spices.	Temple and Cemetery of Confucius and the Kong Family Mansion
Roof waterproofing 1	Waterproof layer: stone tile; Lime mixed with loess in a ratio of 3: 7; "Tin back" waterproof layer, is a lead-tin alloy sheet.	Four Gates Pagoda
Roof waterproofing 2	"Grey back" waterproofing: It is made of lime, chop the hemp rope (plant fiber), green ash (graphite containing impurities) and other materials mixed into a slurry. It is used in a manner similar to modern cement mortar, which is applied to the joints, nodes and layer of the roof and cured to form a hard waterproof coating. Install roofing tiles	Hongjialou Cathedral; Temple and Cemetery of Confucius and the Kong Family Mansion
Woodwork	Use mortise and tenon to connect components	Temple and Cemetery of Confucius and the Kong Family Mansion

Table5.2 Strategies(respondent's point of view)towards the restoration of heritage buildings

Option	Subtotal	Percentage
Leave it as it is, nothing has changed	454	 62.53%
On the basis of the original, modern technology can be used appropriately Use the original process whenever possible Build a new one	438	 60.33%
Use the original process whenever possible Build a new one	479	 65.98%
Build a new one	0	 0%
Number of people	726	

REFERENCES

- Cultural Relics Protection Law of People's Republic of China.(2017).
Available at:
<<https://www.cnrencai.com/law/153121.html>> [Accessed at 21 Jul 2022]
- Di Xiaotan,Tian Xin.(2011).Risks and Countermeasures for Reinforcement and Reconstruction of Existing Buildings.*Construction Technology*.(3),4
ISSN : 1002-8498
- Huang Dashu.(2008).Countermeasures to several difficult problems in the maintenance of ancient buildings. *Technology Exchange Collection of the Ancient Building Construction Repair and Maintenance Reinforcement*
Available at:
<https://xueshu.baidu.com/usercenter/paper/show?paperid=37a89fa37c258580e5852a1335ab6899&site=xueshu_se>[Accessed at 26 Jul 2022]
- J. Kent Hsiao & Jale Tezcan.(2012). Seismic Retrofitting for Chord Reinforcement for Unreinforced Masonry Historic Buildings with Flexible Diaphragms, *Practice Periodical on Structural Design and Construction, Volume 17 Issue 3 - August*
- Li Bao & Wang Jinping.(2011). Technical requirements for the maintenance and construction of ancient buildings, *Scientific and Technological Information Development and Economy*, 021(020), pp.218-219.
Available at:
<https://xueshu.baidu.com/usercenter/paper/show?paperid=6c734e8f677ff46d41709c2e1af82217&site=xueshu_se>[Accessed at 25 Jul 2022]
- Liang Sicheng. (1935).Preservation and Renovation Plan of the Confucius Temple in Qufu. Available at <<https://www.doc88.com/p-21573199988066.html>>[Accessed at 25 Jul 2022]

- Liao Zihua, Cai Jiming, Feng Quanhong, Tang Jinyao&Wei Guangrong.(2013).
The application of 3D laser scanning measurement technology in the maintenance and protection of ancient buildings. *Journal of Donghua University of Science and Technology: Natural Science Edition*, 36(4), 5. Available at:
<https://xueshu.baidu.com/usercenter/paper/show?paperid=9f9a09c4735e3a451b9afa1fd2c358df&site=xueshu_se>[Accessed at 28 Jul 2022]
- Liu Xianqing. (2021). Research on the key points and measures of cost control of dangerous old housing renovation projects. Available at:
<<https://doi.org/10.3969/j.issn.1673-0038.2021.15.010>>[Accessed at 23 Dec 2022]
- Lü Zhaoqiu. (2019). Protection and maintenance of historical buildings based on virtual reality technology. *Building Materials Development Orientation*, 17(5), 1. Available at:
<https://xueshu.baidu.com/usercenter/paper/show?paperid=1r0p06n03h2b0p903p7g0t60hf224323&site=xueshu_se>[Accessed at 29 Jul 2022]
- Luo Zhewen & State Administration of Cultural Heritage in Beijing.(2009).The principle of maintenance of ancient buildings and the application of new materials and new technologies----Chinese characteristics in the protection and maintenance of cultural relics buildings. *Institute of Chinese Cultural Relics*
Available at:
<https://xueshu.baidu.com/usercenter/paper/show?paperid=c1e7fa0b972b11797f13536769eedf16&site=xueshu_se>[Accessed at 25 Jul 2022]
- Ma, W., Hao, J.L., Zhang, C. et al. (2022).Evaluating carbon emissions of China's waste management strategies for building refurbishment projects: contributing to a circular economy. *Environment Science Pollution Research* .
Available at:
<<https://doi.org/10.1007/s11356-021-18188-6>>[Accessed at 23 Dec 2022]
- Ministry of Housing and Urban-Rural Development of People's Republic of China.(2021).General Code for Maintenance and Renovation of Existing Buildings. Available at:
<https://www.mohurd.gov.cn/gongkai/fdzdgknr/zfhcxjsbwj/202110/20211013_762457.html>[Accessed at 29 Jul 2022]
- Ministry of Housing and Urban-Rural Development of People's Republic of China.(2021).Notice on further strengthening the protection of historical and cultural districts and historic buildings.
Available at:
<<https://xw.qq.com/cmsid/20210127A01CB800>>[Accessed at 21 Jul 2022]

Ministry of Housing and Urban-Rural Development of People's Republic of China. (2017). Notice on Strengthening the Protection and Utilization of Historic Buildings.

Available at:

<<https://wenku.baidu.com/view/daf80621b7daa58da0116c175f0e7cd1842518b8.html>>[Accessed at 21 Jul 2022]

Ministry of Housing and Urban-Rural Development of People's Republic of China. (2019). Standard for construction of repairing civil building.

Available at:

<<https://www.doc88.com/p-54261817475073.html>>[Accessed at 29 Jul 2022]

National Cultural Heritage Administration, (2012)

Available at:

<http://www.gov.cn/gzdt/2012-07/24/content_2190563.htm>[Accessed at 29 Jan 2023]

Ningwei Zhang, Shan Che, & Feng Xu. (2011). Renovation and restoration of outstanding historical buildings in Qingdao. *Theoretical Research in Urban Construction*, 000(028), 1-4.

ISSN:2095-2104

Petra Kolonko, *Frankfurter Allgemeine*, 1st Oct 2013,

Available at:

<<https://www.faz.net/aktuell/gesellschaft/menschen/deutscher-bahnhof-in-china-nostalgie-plus-shopping-mall-12599551.html>>[Accessed at 21 Jul 2022]

Qin Weiwei. (2005). Examples of historical building maintenance and renovation projects. *Foreign Building Materials Technology*, 26(6), 3.

Available at:

<https://xueshu.baidu.com/usercenter/paper/show?paperid=151t0r00g65v0tt0t41x0j8075733886&site=xueshu_se>[Accessed at 29 Jul 2022]

Second Amendment to the Construction Act of People's Republic of China. (2019)

Available at:

<<http://www.tlrd.gov.cn/tljzw/zfxxgk60/fdzdgknr64/lzyj25/bmgfxwj73/1306277/index.html>>[Accessed at 21 Jul 2022]

Stovel, H. (1998). *Risk preparedness: a management manual for world cultural heritage*. Available at:

<https://www.iccrom.org/sites/default/files/ICCROM_17_RiskPreparedness_en.pdf>[Accessed at 21 Jul 2023]

Tan, S. Y., Olanrewaju, A., & Lee, L. T. (2016). Maintenance of heritage building: a case study from Ipoh, Malaysia. In *MATEC Web of Conferences* (Vol. 47, p. 04003). EDP Sciences.

United Nations Department of Economic and Social Affairs.(2023)
Available at:<<https://sdgs.un.org/goals/goal11>>[Accessed at 21 Apr 2023]

Urban and Rural Planning Law of People's Republic of China.(2019).
Available at:
<http://www.yw.gov.cn/art/2021/1/22/art_1229472051_59229223.html>
[Accessed at 21 Jul 2022]

Yan Weijun, & Xue Zhengyu. (2010). Cost control of building maintenance based on LCC theory. *Marketing Management Review*. (10), 2. ISSN:1009-2994

Yang Xin.(2014). Chinese ancient building maintenance and protection values. *Chinese Cultural Relics Science Research*(2), 5.
Available at:
<https://xueshu.baidu.com/usercenter/paper/show?paperid=1bea7d4c62fa455bc5091236f0d6995d&site=xueshu_se>[Accessed at 28 Jul 2022]

Zhang Zuqun. (2016). On the "authenticity" of the "collapse-reconstruction" of Leifeng Pagoda. *Research on Heritages and Preservation* (3), 7.
Available at:
<<http://qikan.cqvip.com/Qikan/Article/Detail?id=89676672504849544851484857>>[Accessed at 23 Dec 2022]

Zhao Zhongshu.(2002).Characteristics of China's famous historical and cultural cities and some issues in their protection. *Urban Planning*.
Available at:
<https://xueshu.baidu.com/usercenter/paper/show?paperid=0c28715b9b7ec115faec9c0781c92c63&site=xueshu_se> [Accessed at 21 Jul 2022]

Appendix A--Report on the investigation of the Four Gates Pagoda

1. Basic information of the building

Name	Four Gates Pagoda
Location	Licheng District, Jinan City, Shandong Province, China
Completion time	AD 611, Sui Dynasty
Architectural style	One-storey, pavilion-style pagodas
Structural form	Square single-storey pavilion-style stone pagoda with a height of 15.04 meters. All elements of the structure are symmetrical with four identical sides each facing one of the four cardinal directions (East, West, South, North).
Building material	The material is stone bricks, quarried in the local mountains and belongs to limestone.
The original purpose of the building	Religion, Buddhism
The value of the building	
Protected list: The pagoda has been listed as a Major Historical and Cultural Site Protected at the National Level since 1961.	
The main current use of the building: Tourist attractions	
Social benefits and others: The Four Gates Pagoda is the only surviving Sui Dynasty stone pagoda in China, and it is also the earliest and most complete surviving single-storey pavilion-style stupa in China.	

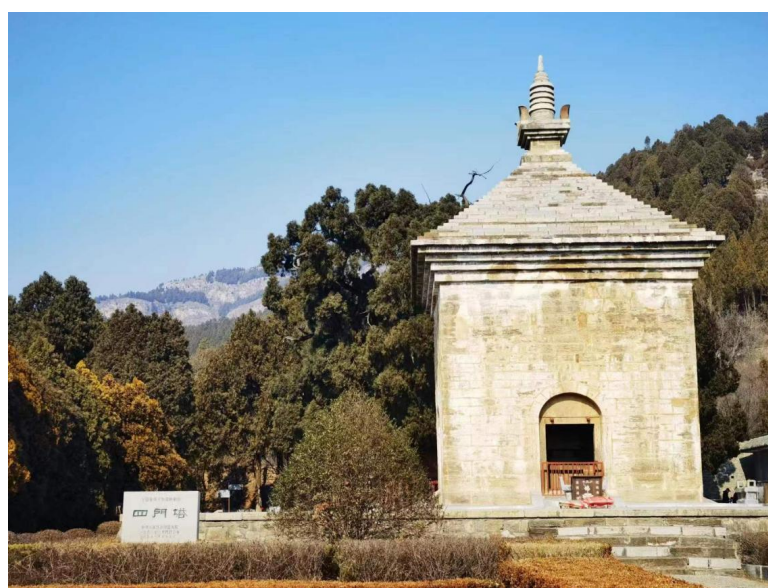


Figure: Four Gates Pagoda

2. Protection, repair and retrofitting

Regarding the maintenance and retrofitting of the Four Gates Pagoda, there are three times that can be verified and recorded. These three were in 1951, 1972 and 2012.

2.1 Salvage protection in 1951

Because the People's Republic of China had just been founded at that time, the documents were not preserved enough, and the investigation of the repair was only based on a handwritten report. The report was written by Lu Dahuang, a scholar and construction manager, and submitted to the competent authority at the time, the Cultural Relics Protection Committee of the People's Government of Shandong Province.

Due to its age, weathering and war, the Four Gates Pagoda was seriously damaged and faced the risk of collapse. According to the report of Lu Dahuang, cracks appeared on all sides of the tower at that time, and the capstones of the four gates were broken. Plants already grow at the top of the tower.

In this repair, three iron hoops were added to the exterior of the tower. To the north of the base of the tower, it is made of gray stone to the outside of the eaves. Internal and external cracks are wiped with soil-lime. The trees at the top of the tower were all uprooted.

2.2 Reinforcement in 1972

In 1971, the State Administration of Cultural Heritage decided to allocate special funds for the maintenance of the pagoda, and issued instructions to "strengthen the base of the tower and repair the top of the tower". In 1972, the maintenance work officially began, strengthening the base and body of the tower.

(1) Condition before construction

According to the survey and study of the tower, the damage of the tower is as follows: the tower is in disrepair due to historical changes, wind and rain erosion, and the uneven settlement of the foundation of the north and south walls, so that the tower body is tilted to the southwest by twelve centimeters. There are two cracks in the western wall, the largest gap is twelve centimeters; two cracks in the east wall; The four arches have varying degrees of cracking and sagging. Because of the sinking of the tower core column and the uneven settlement of the outer wall of the tower, the triangular stone beams resting on the tower core column and the outer wall were all broken, and two-thirds of the stone arch plate was broken. The top of the tower was weathered and broken, and the eaves stone was damaged.

(2) Strengthening the tower foundation

A nine-meter-square retaining wall was built around the tower to block soil erosion and prevent the tower base from slipping. Slope protection stones were built around the outer wall of the tower to prevent rainwater from directly eroding the foundation soil of the tower, so as not to sink or sink unevenly over time.

(3) Strengthening the tower body and repair the top of the tower

① When repairing the top of the tower, the outer wall is dismantled to the outer cornice, the tower core column is dismantled to the inner cornice, the load-bearing triangular beam and stone arch plate are removed to reinforce and bond, and the broken stone triangular beam is solidified with epoxy glue on the ground and then drilled and reinforced with steel bars. The three missing stone triangular beams were added as they were, and then the stone triangular beams were placed on the core pillars of the tower and the outer wall of the tower. The fracture of the stone arch plate is bonded and solidified with epoxy glue and then placed on the stone triangular beam. Its arch foot rests on the outer wall on one end and on the central pillar of the tower.

②The four door arches of the tower, the drooping part of which is topped up to the original position with a jack and squeezed with an iron wedge. A dark plate is placed horizontally under the arch stone to support the door arch stone so that it does not sag again.

③ The cracks of the exterior wall are repaired, and the cracks are repaired with fine stone concrete, and the cracks are repaired with cement slurry if the cracks are small.

④The three stone Buddha seats in the east, west and south of the pagoda have been replaced as they were.

⑤The new stones and repaired cracks inside and outside the tower are painted with black-alum(ferrous sulphate, FeSO_4) to make them old.

(4) A discovery during this construction

In 1973, when the top of the tower was repaired above the central pillar of the tower, a Buddhist relics letter and the relic were discovered. More importantly, it was during this repair that the age of the Four Gates Pagoda was finally confirmed. On a stone slab, the words "Daye Seven Years Built" are engraved, according to which it is finally determined that the construction date of the Four Gates Pagoda is the Sui Dynasty, and the time of completion is the seventh year of Sui Daye (611 AD).

2.3 The most recent repair in 2012

(1) Condition before construction

After repairs in the early 70s, the tower had not undergone major repairs for nearly 40 years by the end of 2011. The Scenic Area Management Committee found that at present, the tower has problems such as leakage at the top of the tower, cracks in the tower body, and masonry, especially the leakage has a serious impact on the tower body and the Buddha statues in the tower.

(2) Innovation

① Three waterproof layers to eliminate leakage problems.

Stacked stones and "three-seven gray soil" (a substance mixed with 30% lime and 70% loess) are the two original waterproofing layers at the top of the tower.

However, in such waterproof practices, small gaps and holes may lead to new leaks at any time. To this end, the design unit added a "tin back" waterproof layer to the bottom of the entire top of the tower. "Tin back" is made of lead-tin alloy, which has good ductility and stability, and is often used in buildings such as the Forbidden City in Beijing, with obvious protection effects. After this renovation, the "tin back" layer became the third line of defense for waterproofing the top of the tower. In this way, if the top of the stone tower has a problem again for a long time, the "three-seven gray soil" layer will play a second waterproof role, and if this layer cannot block water seepage, the "tin back" layer will become the third line of defense.

② Integrated protection of scenic spots and application of 3D virtual models

For the protection of the Four Gates Pagoda, the National Cultural Heritage Administration issued a directive, suggesting that the Four Gates Pagoda and the Thousand Buddha Cliff statue next to it should be protected in the same scope and jointly protected.

For the protection of the Thousand Buddha Cliff site next to the Four Gates Pagoda, it is still in the stage of surveying. The surveying and mapping staff said they used some of the most advanced high-tech equipment in the industry. Such as 3D scanners, high-resolution digital cameras, etc. Detailed information about ancient buildings and detailed sculptures can be collected in all directions, and with this information, they will produce a highly realistic virtual 3D model, which can show the whole picture of the artifact and any subtle places through a computer. According to the technical standards of cultural relics information collection, the virtual 3D model displayed

can be almost the same as the physical object seen with the naked eye.

(3) Construction process

In February 2012, the restoration project of ancient architectural relics of the pagoda was officially launched. Cui Dayong, director of the Jinan Municipal Cultural Relics Bureau, said at the launching ceremony that leakage treatment, pollution removal and status quo renovation will be carried out on the basis of maintaining the original appearance of ancient buildings in accordance with the requirements of the Guidelines for the Protection of Cultural Relics and Monuments in China and the Measures for the Management of Cultural Relics Protection Projects. The basic process of tower roof construction is: remove the top masonry, lay a waterproof layer, and reset the top masonry.

On February 19, the dismantling of the top of the four-gate tower officially began, and the construction crews carefully removed the bondage between the top orb and the lower components of the tower, and then transported them to the ground. The orb component, which appears to be small at the top of the tower, is actually more than 1 meter tall and is estimated to weigh 75kg.

The various components removed from the top of the tower are numbered. The position relationship and spacing between the components are measured, recorded, and photographed. On the east side of the top of the tower, a passage is specially erected from the lower part of the tower, from which the dismantled building components will be transported to the ground by a small lifting equipment at the end of the passage, and then placed on the side of the construction site in turn.

Zhai Yanbin, captain of the maintenance and construction team of the Four Gates Tower, said: The construction period of this repair project is secondary, and the most important thing is to ensure the safety of cultural relics and the quality of the project. The construction progress will definitely be slower at first.

In the process of dismantling the top of the tower, the construction personnel found that the stones at the top of the tower had cracked, and the cement at the connection between the stones and the stones had bulged, which was the main cause of leakage at the top of the tower.

From the recollections of construction workers, it is known that before the repair of the four-gate tower in 1972, the filling on the top of the tower was chaotic stone and "three-seven gray soil" (a substance mixed with 30% lime and 70% loess), and when it was repaired in 1972, it was changed to cement mortar. Changes in the filling material may also be a cause of leakage at the top of the tower.

At the end of May, the construction of the top of the tower was completed, and workers treated the gaps and water stains in the tower.

At the beginning of July, the construction of the project was finally completed. During the rains in July, there was no leakage in the tower chamber and no water standing on the top of the tower. After several days of continuous observation, there was still no sign of leakage in the room.

Appendix B--Report on the investigation of the Hongjialou Cathedral

Basic information of the building

Name	Hongjialou Cathedral
Location	Licheng District, Jinan City, Shandong Province, China
Completion time	1905
Architectural style	Gothic Revival
Building material	The material is stone bricks, quarried in Jinan and belongs to limestone.
The original purpose of the building	Places of Christian activity
The value of the building	
Protected list: In 2009, it was announced by the State Council as a national key cultural relic protection unit.	
The main current use of the building: 1. Tourist attractions 2. Places of Christian activity	
Social benefits and others: Well-known attractions in Jinan; The largest Catholic church in North China	



Figure: Hongjialou Cathedral

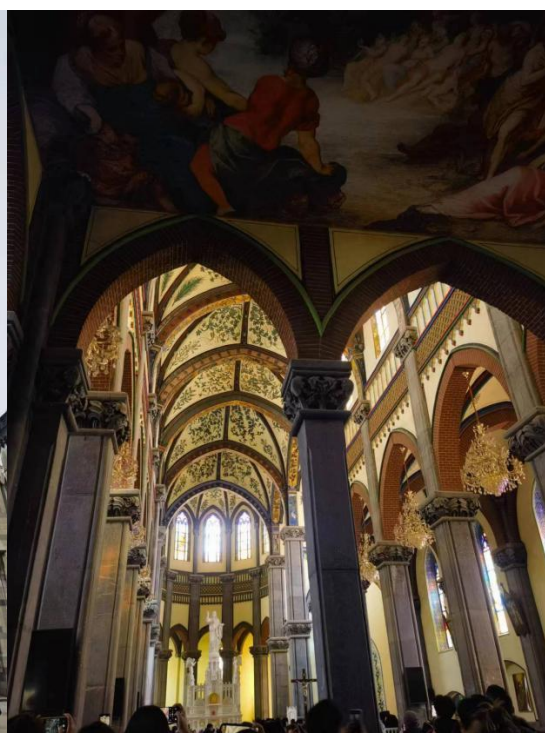


Figure: Internal frescoes with ceilings

2. Protection, repair and retrofitting

Since the completion of Hongjialou Cathedral is not particularly old, there has been no reinforcement of the main structure.

2.1 In 1985, the first renovation on record

In April 1985, the government allocated special funds for the comprehensive restoration of 6 crosses, 96 stone towers, and church frescoes, icons, floors, kneeling benches, altars, lamps and other facilities. But this time the repair lacked detailed records.

2.2 In 2009, the church bell tower was replaced with a new bell

On September 28, 2009, Shandong Compass Watch Company completed the commissioning of the new large bell in the church bell tower. On October 1, 2009, the new bell was installed and officially opened.

The new clock has a white dial and weighs about 120 kg. The dial is made of polycarbonate sheet, which is resistant to acid and alkali, can resist wind, sun and rain for a long time, and the dial is not easy to change color, which can ensure the landscape effect of the clock. The Roman numerals on the dial are made of high-quality steel tube material and are treated with fluorocarbon paint, so that the Roman numeral scale can resist acid and alkali, and remain unchanged. The stiffeners on the back of the hand allow the hand to function even in high winds. The clock adopts LED rear projection lights, emits white light, high brightness, and the time illuminated by the rear projection lights can be set, and the lighting time can be set according to the change of season.

Before the reopening of the bell, the designers had four schemes, and the four dials in

the scheme were more solemn and elegant, which complemented the Gothic style of the church. All 4 dials are wrought iron dials, and the surface has been treated with special fluorocarbon paint, which is resistant to acid and alkali, and is not easy to rust and corrode. After consulting Bishop Zhang, the relevant departments and technicians finally adopted the first plan.

This seems like a very ordinary project. However, it is worth noticing that the original clock has been out of failure for many years before it was replaced. In addition, according to the bishop, the Church had been trying to restore the bell, but had not succeeded due to lack of capacity (funds, technology, etc.). So, it's worth looking at the background of the project and what goes beyond it, what made the project possible?

One of the reasons is the spread of the media, the attention of the masses and the support of all sectors of society. The failure of the bell was published in the newspaper and attracted attention from all sides. Shandong Compas Watch Company offered to undertake the maintenance work, which further contributed to the restoration of the watch.

Another reason may have something to do with timing node. On the one hand, the bell, which had been faulty for many years, suddenly received widespread attention and was repaired in a short period of time, and began full-scale operation in October. On the other hand, it is also in October that the National Games of PRC will be held in this city. Linking these two aspects, the restoration of the bell tower can make the church more distinctive, and can also attract tourists during the event, which is good for the image of the city. Perhaps it is precisely because of this special time node that the restoration of the bell tower can be helped by all walks of life and proceed smoothly.

2.3 In 2011, a controversial repair

According to church staff, the church has not been repaired since 1985, and now it is obvious that the walls are loose. He claimed that the renovation was chosen because the rainy season had passed and the duration of the repair was expected to be from six months to one year, which was the right time.

The repair consisted of three main tasks:

- ①The rain leakage on the roof of the church is already serious, and the broken bricks and tiles of the roof need to be replaced.
- ②Repair the damaged wall and paint the wall.
- ③Replace the chairs inside the church.

However, there are some risks associated with this repair. As a result, this is not a successful project. The first and biggest problem is that this time the maintenance was not reported, not approved, not adequately planned, almost completely private, or even blind. Because the maintenance of the heritage building was not reported and approved by the relevant departments, the project was stopped. This is one of the reasons why this repair was not completed. In 2022, the roof repair and protection

"As a national key cultural relic protection unit, if it undergoes major renovations, it must be reported to the State Administration of Cultural Heritage for approval." A staff of the Jinan Municipal Cultural Relics Bureau said that they had not received the relevant approval procedures for the renovation of the church. According to the regulations, the maintenance of the Church should first be reported to the cultural relics department, and then reported to the level by level. The renovation plan must be designed by a unit qualified for cultural relics protection engineering. Construction must also be carried out by qualified units.

According to the law, the renovation of cultural relics should be carried out in accordance with the principle of repairing the old as before, and try not to change the

original appearance. The maintenance of the cultural relics by the unit using the cultural relics must also be carried out under the supervision of the cultural relics department. If the current renovation unit of Hongjialou Cathedral does not have the relevant qualifications, although the repair itself may be well-intentioned, it may inadvertently cause damage to the cultural relics.

On the other hand, according to church staff, although this repair does not seem to have a lot of work, the project is not going smoothly due to tight funds. This may be another reason why this repair was not completed.

2.4 In 2022, a successful retrofitting

Project began and has been completed. The renovation work is as follows:

- ① The complete dismantling of the imbrex and semicircle-shaped tile.
- ② The removal of the roof cement mortar.
- ③ The rework of the “gray back” and tile surface. “Gray back” is a construction process that can play a waterproof role. Plaster the hair mortar (hemp cut lime mortar, the traditional practice is to chop the hemp rope and mix the sand with slaked lime) on the roof panels. Plaster it layer after layer, and compact.
- ④ The replacement of broken and unusable and non-compliant tiles.
- ⑤ The completion of the repair work of the second-story roof, downspout, ridge decoration and so on.

Appendix C--Report on the investigation of the Temple and Cemetery of Confucius and the Kong Family Mansion

1.Basic information of the buildings

Name	Temple and Cemetery of Confucius and the Kong Family Mansion
Location	Qufu City,Shandong Province,China
Completion time	478BC----the earliest recorded More details are provided in report.
Building material	Wood, masonry
The original purpose of the building	Residences, sacrifices, tombs
The value of the building	
Protected list: State Priority Protected Sites in 1961; United Nations Educational, Scientific, and Cultural Organization(UNESCO),World Heritage List (https://whc.unesco.org/en/list/704/)	
The main current use of the building: Tourist attractions	
Social benefits and others: A representative of oriental architectural techniques, and has a deep historical connotation.	



Figure:Temple and Cemetery of Confucius and the Kong Family Mansion
(Source:http://k.sina.com.cn/article_7042248789_p1a3c0305500100k1ot.html#/)

2. Architectural yearbook and features of the buildings complex

Due to the cultural significance represented by the complex, it has been valued by the rulers of the country from the Han Dynasty to the present, and almost every dynasty has construction records about the Confucian Mansion and the Confucian Temple. Many emperors have ordered the expansion and renovation of the Confucian Temple. For example, increasing the number and scale of houses, building new houses, repairing damaged parts, etc.

- In 478 BC, the magistrate sacrificed Confucius.
- In 195BC, the first emperor of the Han Dynasty used the rank of “tailiao” (pig, ox, sheep) to sacrifice Confucius. Since then, the Temple of Confucius has served as a place of national sacrifice.
- In 156 AD, the Temple of Confucius was renovated. (Stele of Ritual Vessels in the Confucius Temple)
- In 168 AD, the walls were repaired and painted. (Shi Chenbei, a stele in Han Dynasty in China)
- In 637AD, expand and rebuilt the Confucius Temple. After this reconstruction, the Temple of Confucius has undergone great changes.
- In 1021, the Temple of Confucius was renovated and expanded.
- In 1412, the Confucius Temple was expanded.
- In 1499, the Temple of Confucius suffered a fire, and almost all of the main buildings were destroyed. Then rebuild.
- In 1538, a new torii was built.
- On June 9, 1724, the Temple of Confucius caught fire due to lightning, destroying 133 houses. Then rebuild. (Liang, 1935)

As can be seen from the above records, the Temple of Confucius has undergone many times of damage, repair, reconstruction, expansion, etc. In the construction process again and again, architectural features from different periods were integrated

into the Temple of Confucius. At the same time, the architectural styles of the past were also affected. For example, it is now difficult to find Han dynasty architecture from the Temple of Confucius, only records on stone tablets remain. The current Temple of Confucius is dominated by buildings from the Ming and Qing dynasties.

3. Protection, repair and retrofitting

3.1 Records of the maintenance of the Confucius Temple in historical records

The Temple of Confucius was originally the former residence of Confucius. (Li Daoyuan, *Commentary on the Water Classic*) The Confucius Mansion was not built until the Ming Dynasty. Records of the restoration are recorded in the stele and in the literature, but details are missing, some ancient books and stone tablets do not have corresponding English names. It is now organized part of these as follows:

- In 156 AD, the Temple of Confucius was renovated. (Stele of Ritual Vessels in the Confucius Temple)
- In 168 AD, the walls were repaired and painted. (Shi Chenbei, a stele in Han Dynasty in China)
- In 637AD, expand and rebuilt the Confucius Temple. After this reconstruction, the Temple of Confucius has undergone great changes.
- In 1021, the Temple of Confucius was renovated and expanded.
- In 1412, the Confucius Temple was expanded.
- In 1499, the Temple of Confucius suffered a fire, and almost all of the main buildings were destroyed. Then rebuild.
- On June 9, 1724, the Temple of Confucius caught fire due to lightning, destroying 133 houses. Then rebuild. (Liang, 1935)



Figure: Report on the fire in the Temple of Confucius in 1723
(Source: <http://www.qfskgj.com/qfbwg/jycc/445.html>)

3.2 Renovation plan in 1935

In 1935, the then government decided to restore the Temple of Confucius. Due to the great significance of the building, the maintenance has received attention from all walks of life. However, the restoration of ancient buildings was unprincipled and standard at that time. In particular, the problem of major renovation of heritage buildings at that time was not stipulated and managed by corresponding restoration principles and technical standards.

In 1935, the project leader, Liang Sicheng completed the *Preservation and Renovation Plan of the Confucius Temple in Qufu*. This is the earliest blueprint for the restoration design of ancient buildings in China, and has a far-reaching impact on China's heritage protection. The program system developed for the national project is complete, the concept is scientific, and the technology is reasonable, which provides examples and standards for the protection and restoration of heritage buildings that was in the ascendant at that time.

The plan includes the project background, restoration principles, construction and repair history, current status and damage, repair practices, construction instructions, construction drawings and cost estimates. The accompanying materials include the relevant historical materials, inscription records, documentary materials and

research results of the Confucius Temple, as well as a large number of hand-drawn design drawings and on-site photos.

The plan requires strict protection of the original appearance from the outside, ensuring structural safety internally, and forming a protection strategy that is different and differentiated from the inside and outside. (Liang, 1935) There are also detailed instructions on how to ensure the original appearance and the stability of the internal structure. For example, in the fourth chapter of the plan, three situations of beam damage in wooden structures are summarized: cracking, bending, and loosening of mortise and tenon joints. And then, make a plan for each situation, propose measures, and draw drawings to illustrate. Although this restoration plan could not be implemented due to the war, it provided guidance for the restoration of many heritage buildings later.

3.3 Dacheng hall of confucius temple repair in 1983

3.3.1 Introduction

Basic information	Dacheng Hall is the main hall of the Temple of Confucius, and it is also the core building unit of the Temple of Confucius.
Condition before construction	The statues and shrines were completely destroyed, and their shape and height were no longer recognizable.
Scope of the project	Reconstruction of the statue of Confucius and the shrine.
Goals of the project	Restore as it is, and achieve the original viewing effect.

3.3.2 Difficulties in construction and countermeasures

The reconstruction required the construction team to be faithful to the original appearance of the statue and shrine, so it was necessary to fully understand their original appearance. However, the damage was too severe and the project team had never seen the original form, which made construction difficult.

(1) Relevant information collection

In order to restore the statue and shrine, the project team carried out a lot of data collection. The team arranged for many people to go to Shandong Provincial Library, Shandong Provincial Museum, Beijing Library, relevant publishing houses, universities, etc. to check materials and look for clues. On the other hand, the team searched for the original appearance of the statue and shrine from the relevant video materials, and finally determined the appearance of the statue and shrine through the review of some video clips and photos. Regarding the specific size, the project team first restored the size of the base according to the remaining base. Then, based on photographs and other images and written materials, the dimensions of the original statues and shrines are measured using the principles of geometry and perspective.

(2) Make statue samples to overcome illusions

Restoring statues in text, pictures, and videos into three-dimensional shapes is not an easy task in a period when technology is not developed and relevant information is lacking. The project team first created a sample of the statue, which based on what it looked like in the photo, simulating the effect under light to determine the shape and color. The production team also invited residents who had seen the statue and shrine in their original form to ask them for their opinions, and finally obtained a satisfactory result.

3.4 A renovation of Kuiwen Pavilion, the main building of the Temple of Confucius

3.4.1 Project Introduction

Kuiwen Pavilion is the main building of the Temple of Confucius, which was built in 1018 AD. The building is 30.1 meters long, 17.62 meters wide and 23.35 meters high. It is a wooden structure building. Due to the erosion of the building for many years, the roof leaked, some wooden components decayed, the tenons were loose, and some

columns were tilted and misaligned.

In 1935, Liang Sicheng and other ancient architecture experts conducted a comprehensive survey and study of the Confucius temple building and formulated a repair plan, including Kuiwen Pavilion, but it was not implemented due to the impact of the war. In April 1983, the Institute of Science and Technology for Cultural Relics Protection of the State Administration of Cultural Heritage and the Qufu Municipal Cultural Relics Management Committee conducted another on-site survey of Kuiwen Pavilion, drew detailed survey drawings and design drawings, and formulated a maintenance plan. In 1985, the Qufu City Ancient Building Restoration Team began construction. The construction began on 4 January 1985 and ended on 1 May 1987.

3.4.2 Scope of project

Dismantling of all three floors of eaves tiles;

Replace decaying rafters, lookout plates, corner beams and other components;

Bonding and reinforcement of non-decaying components with iron parts;

The part of the component tenon pull out is reinstalled and reinforced with iron work;

Part of the columns of the dark floor are braced with wooden diagonal braces;

The dark floor slab bears poor load-bearing, and an auxiliary floor layer is added;

Renewal of square brick floors;

Painting and decoration, etc.

3.4.3 Strategies and maintenance processes in construction

① Number registration of components

Numbering is registered before dismantling components. This is a necessary work for the component to be reinstalled smoothly. According to the staff, at that time, the northwest corner of Kuiwen Pavilion was used as the starting point, and various components were numbered in a counterclockwise direction from top to bottom. After the components are dismantled, they are sorted and stored. In order to ensure the quality of the restoration, photographs were made at the time of the demolition.

② Erect a protective shed to protect the building

At that time, construction was expected to be completed in about two and a half years. In order to protect the exposed wooden components and painted paintings from the rain during this period, a protective shelter was erected. The protective shed is about two meters above the roof and is covered with tarpaulin. To reduce the influence of the wind, the scaffolding under the shed is surrounded by straw mats.

③ Precautions when removing components

When disassembling columns, beams and purlins, pay attention to protecting the mortise and tenon. When disassembling interior components, ensure that the paintings and murals in the interior are not worn. For relatively large components such as beams and columns, each one weighs more than a ton, and it is difficult to disassemble and install. After weighing the pros and cons, the construction team decided that it was not as convenient to transport it to the ground as it was to repair it upstairs. The construction team set up a load-bearing frame next to it, and moved this large component to the nearest frame for repair and reinforcement.

④ Reinforcement of components

Reinforcement methods include chemical material bonding, wooden diagonal brace reinforcement, ironwork reinforcement.

Chemical bonding and filling are mainly used for cracked and split wooden components, such as eaves, square columns. The cracking of the eaves and the rafters was more serious, and it was decided to strengthen them in two steps. The first is to fill the gap with epoxy resin and fill it with a thin wooden strip of suitable size. Second, the square column of each rafter is reinforced with three fiberglass hoops. The specific method is to use a hair dryer to blow the dust in the cracks of the component, and then prepare epoxy resin binder. The binder uses epoxy resin as the main component, and polyethylene polyamine and xylene are added. Cut grooves 8 cm wide and 0.5 cm deep on square columns where splits exist, wrap a glass cloth around them and apply adhesive until it is flush with the column surface.

The method of wooden diagonal brace reinforcement is mainly used in the dark floor of Kuiwen Pavilion. In order to make Kuiwen Pavilion no longer tilt, the dark layer column adopted wooden diagonal brace reinforcement measures. This approach has two advantages: First, the tilt of Kuiwen Pavilion starts from the root of the dark layer column, and its lower column is not inclined. Second, the dark floor has poor light, and the reinforcement treatment is relatively hidden, which does not affect the viewing effect of the entire building. The diagonal brace section is 24×16 cm, and the contacts are connected with iron activities.

In the maintenance of ancient buildings, the use of iron reinforcement is a more commonly used practice. It not only enhances the connection function of the component, but also improves the strength of the component to withstand the load. In particular, the use of different types of iron in concealed areas is a preferable method.

Dark floor diagonal iron work: As mentioned earlier, wooden diagonal braces are used in the dark floor to reinforce, but in order to ensure the overall strength of the dark floor column network, diagonal brace are installed at the upper end of the dark floor corner column to enhance the cross tension and connect the rigidity of the

entire wooden frame.

Beam iron work: When inspecting the first layer of components, it was found that the back half and the front half of the seven short beams were put together with mortise. At that time, only the nail connection was used, but it no longer works, and the bolted steel plate was used to reinforce it in the repair to make it a whole.

Architrave, Wood-plate Lintel iron work: The tenon of the architrave part of the inner eaves is split, and the mortise is deformed. In the state of non-disassembly, a T-flat iron was made at the architrave end, bolted to the beam. Due to structural deficiencies, some column tops are not connected by horizontal members, resulting in the column head tilting to the inside and the bucket arch to the outside. Taking this weakness into account, steel plates 450 cm long, 32 cm wide and 0.8 cm thick were reinforced on top of the architrave of the stigma. To enhance the connection of the wood-plate lintel, the corners are reinforced with ruler-shaped steel plates, measuring 1 m long, 20 cm wide and 0.8 cm thick.

⑤In the construction of square bricks laying the ground, the process of dipping bricks with raw tung-oil was developed. The method is to clean up the square bricks that are processed and chopped, first brush raw tung-oil on the square bricks, then lay the square bricks, and then soak them with raw tung-oil after cleaning and drying, and the oil absorption depth of the bricks is more than 3 cm. The ratio of raw tung-oil to kerosene is 20:1. The square brick brushed with tung-oil is similar to the gold brick effect, and it is improved in wear resistance than the brick without tung-oil. It has high promotion value for future ancient building maintenance projects.

⑥Experiment before making the painting old

According to the construction plan, the interior color painting is maintained, and the replacement components are painted and made old. In order to follow the principle of "try not to change the original state of the cultural relics", the color of the newly

drawn pattern should be consistent with the old one. Materials include emerald green (copper acetoarsenite), iron oxide (red with it), ink, glue, etc

3.5 One Maintenance of the ancient buildings inside the Kong Family Mansion

3.5.1 Project Introduction

Client	Qufu Cultural Relics Bureau
Construction unit	Qufu Sankong Ancient Construction Engineering Management Office
Supervision unit	Beijing Hualinyuan Engineering Consulting Co., Ltd
Design unit	Qufu Anhuaitang Cultural Relics Engineering Design Co., Ltd
Scope	Inner house gate, side door; Sleeping hall; A complex of ancient buildings from the inner house gate to the last five rooms; The roof, walls, floors, wooden components and paintings of the above parts.
Repair principles and standard specification	1. Law of the People's Republic of China on the Protection of Cultural Relics, 2015 2. Principles for the Conservation of Heritage Sites in China, 2015 3. Regulations of Shandong Province on the Protection of Cultural Relics, 2010 4. Measures for the Management of Cultural Relics Protection Projects, 2003
Start and completion times	10/4/2017----30/10/2021
Project objectives	Completion of the renovation of the project area so that the heritage buildings are fully protected

3.5.2 Construction process

①Roof work

Inspection of pre-construction conditions	<p>Upon examination, the following damage was found:</p> <p>Broken roof tiles;</p> <p>The main ridge, the vertical ridge brickwork is salt-efflorescence;</p> <p>Between the imbrex, between the imbrex and the tegula, there is binder shedding, accompanied by weeds;</p> <p>The wooden base of part of the roof decayed.</p>
Process	Roof dismantle and base layer inspection
	Re-installation of roofing
	Inspection and filling of the roof after installation
Strategies for achieving project objectives in terms of processes	<p>Use text, drawings, photos, videos and other means to record the current situation of the roof as an integral part of the repair project data. Before the removal of the tiles, do a good job of protecting the interior and exterior eaves decoration and color painting. When removing tiles, remove the exterior decorative tiles first. Use tools such as brick knives and shovels to avoid damage to the tiles. The removed tiles are then sent to a designated site for preservation. Tiles are stored according to the classification of cover tiles, bottom tiles and hook drops, and statistics. The scope of statistics includes the specifications, sizes, kiln marks, number and names of tiles and ridged base parts.</p> <p>The wood base layer of roof is brushed with CCA(Chrome Copper Arsenate) preservative.</p>

②Walls and floors

Inspection of pre-construction conditions		Upon examination, the following damage was found: The ground is fragmented; The apron is damaged and broken, part of the apron is missing, and the drainage function is lost; Part of the wall cracked and the brick cracks expanded
Process	Walls	Partial demolition of the wall; Cut out some bricks with severe salt-efflorescence. Shovel the hollow wall skin, clean the floating soil, nail the hemp and re-plaster.
	Floors	Remove the severely damaged floor tiles and gray soil bedding, redo the 3:7 lime-soil cushion and pave floor with bricks. Replacement of damaged bricks, bonding fractured stone components.
Strategies for achieving project objectives in terms of processes		When demolishing old walls, sort out, check and count old bricks that can continue to be used. It was rebuilt according to traditional practices. When laying new floor tiles, traditional materials are used, with a mixture of lime and loess as a bonding layer. After the laying is completed, apply 2 coats of tung-oil to the surface of the floor tiles.



后堂楼方砖地面铺墁



后堂楼散水地面钻生桐油

Figure: Laying floor tiles (left) ,applying tung-oil to floor tiles (right)

Source:http://image109.360doc.com/DownloadImg/2022/10/1117/253942157_7_20221011055137383.png

③Repair and reinforcement of wood elements



Inspection of pre-construction conditions	<p>Upon examination, the following damage was found: The pillars supporting the eaves appear decayed at the roots; Some components are misaligned, tilted and cracked; The tenon and tenon joints of the wooden components appear loose.</p>
Process	<p>Repair of cracked parts of components; Resets the offset component; Reinforce loose mortise and tenon.</p>
Strategies for achieving project objectives in terms of processes	<p>For slight cracks in the component, directly reinforced with iron hoops. The iron hoop is ring-shaped, and the joint is firmly connected with bolts or large hat nails. If the crack is wide, first use a wooden strip to make up for it, and fill it with epoxy resin caulking and gluing firmly.</p> <p>Lift a sinking member or support an inclined component with a jack; Use a cable to pull the tilted, loose tenon component to reset it.</p> <p>The loose part of the tenon at the connection of the beam and column is fixed with "staples"(Chinese called 'Ba ding'. An iron product shaped like a staple is often used to reinforce wooden structures to connect two components.). It is to limit the relative displacement between the mortise and tenon from the perspective of increasing the stiffness of the joint, so as to carry out reinforcement.</p>

④Painting

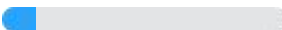
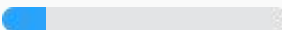
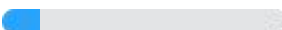
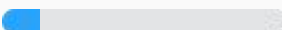
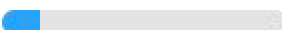
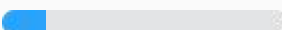
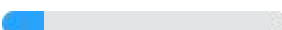
Inspection of pre-construction conditions		Upon examination, the following damage was found: The surface appears stained, hollowing and peeling.
Process	Clean	Remove dust, bird droppings, oil, water stains, etc.
	Paste the pieces	Re-paste hollowing and peeling layers of paintings.
	Paint	The color follows the old color and does not affect the overall effect.
	paste paper	Paste paper on the surface of the ceiling. The function is to beautify and play a certain protective role on the roof.
Strategies for achieving project objectives in terms of processes		<p>Use a soft brush to remove dust directly from the wood components. Then gently scrub with a cotton ball dipped in water, and the areas that are difficult to remove can be scrubbed with EDTA(Ethylene Diamine Tetraacetic Acid) solution.</p> <p>Due to age, the painted layer has hardened. The debris is softened before being re-pasted, softened with hot steam, and then re-pasted, using animal glue. For small areas, a syringe is used.</p> <p>In the paste, in order to preserve the original architectural style, the traditional Chinese pasting method is adopted.The first is to make a paste, which is made by mixing flour, water, spices.The second step is to glue the two sheets of paper together with a paste and compact them into one.Then paste the entire ceiling by the paper. Since the joints of the paper may be uneven, it needs to be leveling.</p> <p>The paper is cut into rectangular shapes, all smeared with paste, and arranged like fish scales, which is called "row fish scales" by workers.Until the surface is relatively flat, paste the last layer of paper.</p>

Appendix D--Questionnaire results

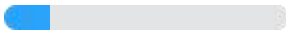
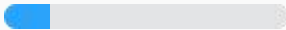
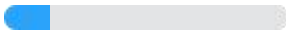
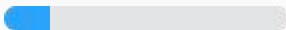
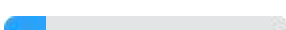
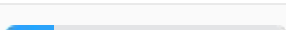
1. Gender: (Mark only one)

Option	Subtotal	Percentage
Male	344	 47.38%
Female	382	 52.62%
Number of people	726	

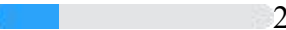
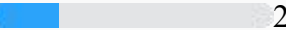
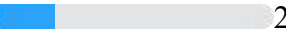
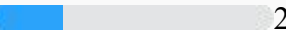
2. Geographic region: (Mark only one)

Option	Subtotal	Percentage
East China	87	 11.98%
North China	115	 15.84%
Northeast China	100	 13.77%
Northwest China	102	 14.05%
Southwest China	98	 13.5%
South China	114	 15.7%
Central China	110	 15.15%
Number of people	726	


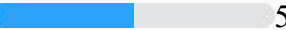
3. Working position: (Mark only one)

Option	Subtotal	Percentage
Design	122	 16.8%
Construction	120	 16.53%
Supervision	122	 16.8%
Developer	119	 16.39%
Relevant competent department	112	 15.43%
Others	131	 18.04%
Number of people	726	

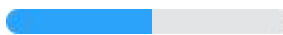
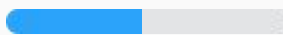
4. Working Experience: (Mark only one)

Option	Subtotal	Percentage
Less than 1 year	180	 24.79%
1 - 2 years	183	 25.21%
3 - 5 years	171	 23.55%
More than 5 Years	192	 26.45%
Number of people	726	





5. Is your city listed as a state-list famous historical and cultural cities? (Mark only one)

Option	Subtotal	Percentage
Yes	357	 49.17%
No	369	 50.83%
Number of people	726	




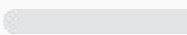
6.Are there any heritage buildings or historic buildings in your place of residence or domicile? (Mark only one)

Option	Subtotal	Percentage
Yes	374	 51.52%
No	352	 48.48%
Number of people	726	




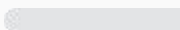
7.How well heritage buildings or historic buildings are preserved, based on what you have seen or known through other means: (Mark only one)

Option	Subtotal	Percentage
Very good	178	 24.52%
Good	200	 27.55%
Acceptable	171	 23.55%
Poor	177	 24.38%
Number of people	726	


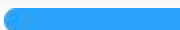
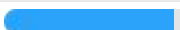
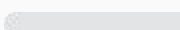
8.In your opinion, a historic or heritage building is well protected because it looks like: (mark one to three)

Option	Subtotal	Percentage
No visible damage	473	 65.15%
No rain leakage	438	 60.33%
Historical features have been preserved	471	 64.88%
Clean and tidy, like a new building	0	 0%
Number of people	726	



9. In your opinion, a historic or heritage building is not well protected because it looks like: (mark one to three)

Option	Subtotal	Percentage
Lack of cleanup, overgrown with weeds	457	 62.95%
Lost its historical character	447	 61.57%
Commercialization is too serious	435	 59.92%
Obvious damage or structural safety issues	0	 0%
Number of people	726	

10. What do you think are the deficiencies in the protection of heritage buildings (if any)? (mark one to three)

Option	Subtotal	Percentage
The building lacked protection and fell into disrepair	454	 62.53%
The heritage buildings are not in harmony with the surrounding environment	456	 62.81%
Tourism is overdeveloped and the commercial atmosphere is too strong	437	 60.19%
Damage was caused during the protection process of the building	0	 0%
Number of people	726	



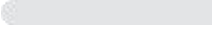
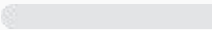
11. Have you heard of the *Cultural Relics Protection Law*? (Mark only one)

Option	Subtotal	Percentage
Yes	359	 49.45%
No	367	 50.55%
Number of people	726	





12. In your opinion, what are the main risks in the maintenance and retrofitting of cultural relics buildings? (Mark only one)

Options	Completely disagree	Disagree	General	Agree	Strongly agree
Unauthorized alteration by building managers, change of building use, etc	0(0%)	1(0.14%)	373(51.38%)	352(48.48%)	0(0%)
Unsafe use of electricity	0(0%)	1(0.14%)	381(52.48%)	344(47.38%)	0(0%)
Relevant laws and norms need to be improved	0(0%)	0(0%)	372(51.24%)	354(48.76%)	0(0%)
The qualifications of relevant units are not up to standard	0(0%)	0(0%)	369(50.83%)	357(49.17%)	0(0%)
The inspection of the building is wrong	0(0%)	0(0%)	362(49.86%)	364(50.14%)	0(0%)
Limited materials and technology	0(0%)	0(0%)	349(48.07%)	377(51.93%)	0(0%)
Blind construction	0(0%)	0(0%)	394(54.27%)	332(45.73%)	0(0%)

13. The maintenance of heritage buildings is necessarily time- and money-consuming. How do you evaluate the financial expenditure and tourism inconvenience caused by this? (mark one to two)

Option	Subtotal	Percentage
Under the premise of ensuring that the purpose is achieved (the ancient buildings are indeed properly protected), it is understandable that these situations occur.	544	 74.93%
Before protecting a building, the government department should make a detailed assessment of such situations, give a conservation plan, and obtain the consent of the local people.	544	 74.93%
This is not necessarily a bad consequence, because until protection programmes are mature, there is a need to be tolerant of situations such as fiscal deficits.	0	 0%
If the cost is too high, maintenance is not necessary	0	 0%
Number of people	726	

14. What attitude do you think should be taken towards the restoration of heritage buildings? (mark one to three)

Option	Subtotal	Percentage
Leave it as it is, nothing has changed	454	 62.53%
On the basis of the original, modern technology can be used appropriately Use the original process whenever possible Build a new one	438	 60.33%
Use the original process whenever possible	479	 65.98%
Build a new one	0	 0%
Number of people	726	