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Analysis of fire risk and fire prevention of architectural heritage: A case study of mount wutai in China

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Abstract. As precious historical and cultural heritages in China, ancient architecture belongs to non-renewable resources. However, in recent years, fires in ancient buildings occurred from time to time, causing irreparable losses to China's precious historical and cultural heritage. In order to explore the existing problems of fire safety in ancient buildings and better prevent fire accidents, this paper starts with an introduction of the structural characteristics of ancient buildings in China, and then, on the premise of combining the characteristics of geographical culture, architectural structure, and materials of Wutai Mountain temple group, the paper also analyzes the fire risk of ancient buildings. According to the practical work experience in fire protection of Mount Wutai, feasible and reasonable fire protection measures of ancient buildings are put forward, including the enhancement of fire resistance of building materials, the related equipment and system, and the safety management, so as to minimize the fire risk and fire loss and achieve the purpose of protecting gorgeous ancient building civilization.

Keywords: Wutai Mount, architectural heritage, temples and ancient buildings, fire hazards, fire protection.

1. Introduction

According to the *Convention on the Protection of World Cultural and Natural Heritage*, heritage has historical, cultural, social, scientific, and artistic value, and is the civilization characteristic of human development and inheritance of historical roots. Cultural and architectural heritage is also the witness of history [1]. In the World Cultural Heritage list, most of them are cultural relics and ancient buildings, so it is extremely important to reduce the fire risk of historical buildings. Although, the value of the ancient architecture of China as the treasure property of the Chinese nation's 5000 years of civilization is inestimable, in the current period of rapid development of urbanization, the transformation and reuse of the architectural heritage are inevitable. However, there are great risks in the development, protection, and restoration of historical buildings. Since most Chinese cultural relics and ancient buildings are wooden structures, fire is one of the most dangerous factors in the protection of cultural relics and old buildings [2]. A fundamental reason for the existence of fire in ancient buildings is its own architectural characteristics, and the fire safety work of ancient buildings is closely related to the safety of cultural relics and personnel. Mount Wutai is not only a famous religious site in China but also enjoys a high reputation at home and abroad because of its abundant natural and cultural resources. The numerous Buddha statues, stone carvings, wood carvings, embroidery, portrait murals, and calligraphy in the scenic spot not only attract tourists from home and abroad but also draw

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the attention of scholars [3]. Based on the actual work of fire protection of old buildings, this paper considers the fire causes and fire prevention measures of ancient buildings and studies the fire risk reduction of historic buildings from three aspects, taking Mount Wutai as an example. Finally, the causes of fire in old buildings are discussed and some countermeasures for the fire safety of historical buildings are put forward. In view of this, this paper can comprehensively consider the economic, cultural, social, and environmental factors of cultural relics and ancient buildings, establish the fire protection system of wooden buildings, better solve the fire-related risks, and rationally plan, analyze, and repair historical buildings, which has historical and social significance for the development of sustainable heritage.

2. Background information

2.1. The concept of cultural relic and architectural heritage

On the basis of *The World Heritage Convention*, cultural relics are the relics left by mankind in the process of historical development and are valuable historical and cultural heritages of mankind. Immovable cultural relics are basically historical relics, such as historical buildings, ancient sites, ancient tombs, and memorial sites. They reflect the social activities, social relations, ideology, and the natural ecological environment of human beings in different periods. Cultural relic and architectural heritage is the general name of various buildings and structures left over by various dynasties with a long history and a certain cultural relic value and historical value [1]. Most of the existing ancient buildings are concentrated places for religious and tourist activities, which are the focus of cultural relics protection and also the key units of fire safety.

2.2. The value of cultural relic and architectural heritage

Cultural relics and architectural heritages reflect the wisdom of the ancient working people and allow scholars to have a deep understanding of social politics, economy, culture, art, and religious beliefs [4]. In other words, ancient buildings are a testimony of history with great value. They can reveal past events and the objective law of the development of human society, thereby promoting the development of contemporary and future society. Architectural heritages are of great significance, which can be summarized as follows: First, they provide evidentiary value of past customs and habits, techniques, and cultural elements; second, they provide scientific value of offering opportunities for scientific research or archaeological discovery; third, they provide symbolic value of monuments of cultural, religious, or historical significance; at last, they provide functional value in situations where buildings play an important role (e.g. hospitals).

2.3. An introduction to Mount Wutai in China

China's long history has created a splendid Chinese culture. Historical buildings are an important part of Chinese culture, as well as an important heritage and symbol of national civilization. Most of the ancient buildings in China are made of traditional wooden frames and mixed structures of brick and wood. Fire prevention is an important task in the work of protecting architectural heritage [5]. Mount Wutai of China is located in Xinzhou City, Shanxi Province. It ranks first among the four famous Buddhist mountains in China and is one of the five Buddhist holy places in the world, along with Lumbini Garden of Nepal, Deer Field Garden of India, Bodhgaya, and Zhusinagar. It was inscribed on the World Heritage List by United Nations Educational, Scientific, and Cultural Organization (UNESCO) in 2009. There are 124 temples in Mount Wutai, which have a long history and a large scale. Among them, the Five Ye Temple and Wenshu Temple are the most vigorous, and there are often uncontrolled fires. In 2020, due to the collapse of power lines, Wuye Temple and Baiyun Temple caused large forest fires [6]. Thus, studying the fire causes of cultural relics and historical buildings and enhancing their fire protection accordingly is the long-term focus of fire control work in Mount Wutai.

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3. Fire hazards of architectural heritage in Mount Wutai

3.1. Architectural characteristics

The buildings of Mount Wutai are mainly temples with a long history. The earliest temples were built in Tang Dynasty, Song Dynasty, Yuan Dynasty, Ming Dynasty, and Qing Dynasty. The low fire-resistant wood materials and the building structure of Mount Wutai temples are the main reasons for the high occurrence of fires in ancient buildings. As shown in Figure 1, the temple of Mount Wutai is mainly composed of the wood structure and brick-wood structure, and the main building materials are pine and nanmu rich in oil. With the wind and sun for hundreds of years or even thousands of years, the wood of historical buildings of Mount Wutai has been dried, and the water content in the wood is very low. Once a fire occurs, the turpentine will immediately become a combustion-supporting substance, and the fire resistance is extremely poor. The low fire resistance rating also leads to a sharp increase in the probability of fire accidents in hot summer [7]. At the same time, there are many cracks and splicing gaps in the wood of the temple, and most of the ventilation conditions are good. The annual wind of Mount Wutai is 5-6, so the fire spreads quickly. In addition, there are many inflammable hangings such as decorations and curtains in the temple. They will become a risk factor for the vertical spread of the fire, which can quickly expand into the air to form a three-dimensional fire. Moreover, the group layout of the wooden structure is not conducive to evacuation. As seen in Figure 2, many of the structures of cultural relics and ancient buildings in Mount Wutai have high roofs and airtight interior structures, which provide good conditions for burning and flame spreading. Once a fire occurs, the temples will not be able to discharge the internal heat and smoke in time, resulting in rising indoor temperature, which is easy to reach "flameout" and leads to collapse. This is also the main reason for the large-scale burning of cultural relics and historical buildings [8].

Figure 1. Corroded wooden wall (Photo credit: the author).

Figure 2. Aged staircase (Photo credit: the author).

3.2. Geographical features

In addition, the natural geographical characteristics of ancient buildings in Mount Wutai are also factors that need to be paid attention to. As exhibited in Figure 3, Mount Wutai scenic area has a high forest vegetation coverage rate. Ancient building groups depend on the mountain, and the geographical location is relatively complex. The natural geographical fire risk of ancient buildings in Mount Wutai is mainly the small fire spacing of historical buildings and the lack of fire water source. First of all, temples of the Mount Wutai are located in density, the fire spacing between the buildings did not meet the safety requirements, and even some buildings are completely connected. There is no fire access in line with the code. Once there is a fire, other ancient buildings around will inevitably involved [9]. Taking the Five Ye Temple as an example, there are bell towers, drum towers, side halls, guest rooms on both sides of the main hall, and the fire can spread rapidly along the horizontal and vertical directions. At the same time, if the building lightning protection measures are not in place, the temple may become the object of lightning strikes, which will also lead to the occurrence of fire. Secondly,

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most temples are far away from the fire brigade station. Their own firefighting force is insufficient, and there is no full-time firefighters and effective firefighting facilities. Some temples are located in a remote geographical location. They lack natural water sources and there is no way to transport water to put out fires because of traffic obstacles,. Moreover, Mount Wutai is in an area with a cold and low temperature, which means the natural water source is frozen in winter, and there is a serious shortage of water for fire fighting [10]. In addition, the terrain is complex. Some roads are relatively narrow, and fire trucks can not pass through. As a result, the fire is often out of control without a timely preventive action, and a small fire finally causes a disaster. Same situations apply to the Lingying Temple, Wanghai Temple, Puji Temple, and other temples away from the town.

3.3. Characteristics of function

The functional characteristics of the ancient buildings in Mount Wutai are also important factors affecting the size of the fire. The functional fire risk of the building group of Mount Wutai can be divided into the following three parts: blind areas for the production and daily life fire, unprofessional prevention of the source of the fire, and a lack of fire-fighting equipment.

First of all, the temples bear the function of sacrifice, and there are phenomena such as lighting lamps, burning wax, and burning incense, which will increase the probability of fire [11]. The incense burners in Mount Wutai are mostly located in temples, where a large number of tourists will visit on holiday. A little careless may easily cause a fire. There are also monks living in the temples of Mount Wutai, so the use of fire is unavoidable. However, there is no obvious separation between the living area and the cultural relic protection area, leading to a big hidden danger.

Second, with the progress of society, the number and types of electrical appliances in the temple increase rapidly, and so does the electricity consumption. The risk of electrical fire is also increasing year-on-year. Some temple electrical lines are directly laid on beams and columns. It is easy to cause fire accidents, especially in the holding of Buddhist events when the electricity demand is strong. In that case, there are high security risks [12]. In addition, some monasteries are not doing regular testing of electrical lines. The application of high-load electrical appliances and the phenomenon of private wiring and random connection also exist, which is easy to cause fire accidents.

Finally, many cultural relics and ancient buildings do not take into account the fire protection problem in the initial construction, resulting in poor fire protection infrastructure, which is also one of the reasons for the high frequency of fires. At present, the automatic fire fighting facilities of most temples in Mount Wutai are relatively backward, only a few cultural relics and historical buildings are equipped with outdoor fire hydrants, and most of the ancient buildings are not equipped with fire pools around them, which cannot be applied to large-scale fires. Besides, although some temples have installed simple alarm and sprinkler systems, the false alarm rate of fire detection and alarm devices is high due to the influence of their structure. Even in the later repair process of cultural relics and historical buildings, facilities such as fire tanks are set up according to the ancient fire extinguishing ideas in order to maintain the beauty and characteristics of the buildings, which does not play a large role [13]. It is worth considering that ancient buildings have their inherent architectural style and historical integrity, if the installation of fixed automatic fire extinguishing facilities with high fire extinguishing efficiency in them, it will inevitably have a certain impact on the value of its art and cultural relics, resulting in many technical problems in the fire design and construction process.

3.4. Management characteristics

Although the Mount Wutai Buddhist Association has always attached importance to safety work, the current supervision of civil structures and ancient buildings is still not in place, and there are loopholes in fire management.

As shown in Figure 4, for one thing, with the rapid development of tourism, Mount Wutai temple has become a focus of tourists from all over the world to visit and pay homage to Buddha. The number of resident monks and nuns in the scenic spot reaches more than 5,000 in the peak season, and the annual number of tourists reaches more than 5.8 million, which is greater than its actual capacity [14].

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Some tourists have a weak sense of fire prevention. They throw cigarette butts in the temple. Besides, the management level of each temple and the quality of monks are not the same. When the management is not in place and monks do not pay attention to safety with fire and electricity, fire accidents can occur.

For another, Taihuai Town, the center of Mount Wutai, is a key town. With the rapid development of tourism in Mount Wutai, many cultural relics and historical buildings have been built around supporting entertainment and dining facilities, and some old buildings will also be changed into shops. Arbitrarily changing the nature of the use of ancient buildings and irregular construction of illegal buildings not only destroy the style of cultural relics but also increase the probability of fire in historical buildings. Meanwhile, tourism, accommodation, the catering industry, and people's daily activities are certain threats to the temple fire safety. The fire is likely to spread rapidly if there is a lack of professional guidance personnel. Additionally, if tourists are not familiar with the building, it is easy to cause evacuation difficulties and leads to other secondary disasters [15]. Hence, the prosperity of the tourism industry is a great opportunity for the economic development of China, but there is a certain crisis for cultural relics and old buildings. In the peak period of tourism, the flow of people inside the ancient buildings is large, which can cause an overload of historical buildings, thus greatly improving the probability of fire occurrence.

Figure 3. Temples surrounded by trees that caused an uncontrollable fire [10].

Figure 4. Overburned incense (Photo credit: the author).

4. Fire prevention for architectural heritage

4.1. The enhancement of fire resistance of building materials

The non-renewability of ancient buildings determines the fire fighting strategy: "prevention goes first, and control is combined" [16], that is to say, any addition and adjustment should be kept to a minimum. Therefore, when old buildings are on fire, it is supposed to actively protect cultural relics, strengthen the awareness of prevention, and avoid the action principle of mutual spread.

First, there is a need to strengthen fire protection measures. It is suggested to use special fire-retardant liquid and sealing materials for fire treatment of cultural relics. Modern original building materials with high fire-resistance grade or newer materials can be used to replace the wooden parts. Concrete floor or dry ice and soda blasting technology can be used to repair the building [17], so as to improve the fire resistance limit and maintain the original appearance of ancient buildings.

4.2. The enhancement of related equipment and system

Besides, the public and internal equipment of ancient buildings needs to be strengthened, and the automatic alarm and sprinkler system needs to be set.

First of all, it is essential to rationally arrange the automatic sprinkler system, such as changing the top spray to the side spray, and strengthen the construction of internal facilities by combining the characteristics of the building structure and decoration.

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Second, it is important to equip fire extinguishers according to the design specifications, set up fire hose reels, water pump systems, and lightweight fire hoses as seen in Figure 5, and build rainwater tanks if conditions permit.

Third, it is necessary to set up a proper fire alarm system as demonstrated in Figure 6. Smoke, temperature, and flame detectors have a certain installation height, two to three detectors can be used in combination, and video monitoring systems can be used to set up remote monitoring platforms using Internet of Things (IoT) technology to ensure the alarm effect of the fire alarm system [18].

What is more, there is also a need to strengthen the construction of public facilities, for instance, fire extinguishing bombs (Figure 7), fire extinguishing guns (Figure 8), and fire extinguishing agents. Besides, the roads in Mount Wutai Scenic Area are supposed to be repaired to meet the requirements of fire vehicles [19].

Figure 5. The water pumping system [12].

Figure 6. The fire alarm/smoke detector [12].

Figure 7. Compressed air foam aircraft fire extinguishing bombs [13].

Figure 8. New fire-fighting guns for remote fire extinguishing [13].

4.3. The enhancement of safety management

Finally, it is also necessary to strengthen the safety management of ancient buildings, including fire water supply, electricity communication, and training and education in the scenic spot. Many old buildings were destroyed by fire in China's history, of which human factors accounted for 76.31%, so the fire prevention of historical buildings mainly relied on management [20].

First, under the lead of the Chinese government, departments of cultural relics protection, religion, tourism, meteorology, forestry, water supply and electricity, urban construction, fire, etc. shall be established to unify the planning, management, and implementation of fire safety work in Mount Wutai Scenic Area. Full-time or voluntary fire brigades (firefighters) shall be set up to carry out fire inspection.

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Second, the management of the use of fire and electricity should be strengthened. It is necessary to strictly manage all fire sources, power sources, and various flammable and explosive chemically dangerous things, and set up security facilities at the entrance of important cultural relics and ancient buildings. For example, in the core buildings such as Wuye Temple and Wenshu Temple, open flames are strictly prohibited, incense candles are replaced by fixed lighting fixtures, incense tables are wrapped in copper or placed in glass panels, and residential areas must maintain sufficient fire spacing between temples [21]. In the meantime, combustible materials near ancient buildings are often removed, and the surrounding trees and dead grass should be trimmed in time to prevent the surrounding fires from igniting historical buildings.

At last, fire education must be strengthened. It is important to strengthen the training of monks and nuns and cultural relics management personnel on fire prevention and fire-fighting skills, effectively improve fire control capabilities, and reduce man-made disaster factors. For instance, paste a large number of slogans in old buildings, distribute fire manuals, and use radio and LED screens, where Buddhist terms can be integrated into, for the promotion of fire prevention knowledge [22]. Especially during the tourist season and religious activity days, service teams formed by guides, monks, nuns, security guards, and volunteers should carry out fixed, open, and mobile fire protection publicity, thus improving the safety awareness of the masses, organizing safe evacuation in time, and reducing fire losses.

5. Conclusion

In general, architectural heritage is the wealth of all mankind, who, therefore, has the responsibility of protecting it scientifically. The fire protection of historical buildings is of great significance, and it is also a long-term work. The fire causes of ancient buildings in China include a series of human causes such as a lack of an effective fire control and prevention system, a lack of fire awareness, and circuit failure. Besides, there are non-human factors such as low fire resistance of building materials and inadequate fire protection zones. Consequently, it is vital to continuously strengthen the research on the complexity of fire protection of old buildings, gradually explore the experience of fire prevention and control, actively face the current safety problems of ancient buildings with new concepts and advanced modern scientific fire prevention countermeasures, enhance the concept of prevention, and strengthen the supervision of fire protection of cultural relics units, so as to reduce the fire risk of historical buildings and keep cultural relics away from the danger of fire, create a new situation of fire safety work of historical buildings, and make due contributions to the protection of world historical and cultural heritage.

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