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Fire hazards in heritage villages: A case study on Dangjia Village in China

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ABSTRACT

Fire protection for heritage villages is a complex issue involving multiple factors, especially for heritage villages comprising brick–timber framed buildings. This study aims to investigate fire hazards in heritage villages and to provide an assessment on fire safety. Site investigations were conducted in a heritage village with data collections in terms of four aspects. First, brick wall condition was investigated. Second, the integrity of timber columns was inspected with the measured wood moisture content. Third, the accessibility of fire brigade intervention and active firefighting facilities was assessed. Finally, other fire hazards, such as disordered electrical wiring, were identified. A linear additive model with multiple attribute evaluation was then used to produce a measure of relative fire hazards. This study revealed significant structural deteriorations in the surveyed heritage village. Several identified fire hazard factors were quantified. Specifically, most external columns suffered different types of damage or erosion, and only 26% of the columns remained intact. The average surface moisture content of timber columns was 12.7% with a standard deviation of 5.95%. Only 10% of the roadways in the village were accessible for fire trucks. A single numerical assessment value represented that the fire safety level in the heritage village was low. The study provided actual information for the development of systematic approach and performance-based design on fire protection in heritage villages.

1. Introduction

1.1. Research background

Fire is a major threat to heritage buildings, and a portion of historic building structures disappears every year due to the fire damages. The irreparable damages to historic structures may cause huge losses. Fires not only cause the loss of valued historic buildings and landscapes but also considerably disrupt the sociocultural environment of communities [1].

In China, several dwellings, such as residences, palaces, temples, monasteries, commercial establishments, and government offices, are popularly featured in a courtyard style called "siheyuan". This type of architecture can be found in rural villages, as well as urban suburbs, in the northern part of China. These buildings are usually framed with timber beams, columns, and brick walls, and are built using traditional fire protection concepts. However, the texture of the dwellings may have been deteriorated over a long time, and some of the functions of the buildings may have undergone changes to some extent. For example, many heritage villages have been converted into tourism sites for their historical and cultural values. Thus, potential fire hazards may be incurred on these factors. From the start of 2010 to the end of 2013, 52 fires endangering historic buildings have been reported by the Chinese administration [2]. From 2012 to 2015, several severe fires occurred in heritage villages in China, which prompted the authorities to review the fire protection systems and strategies [3,5]. New rules and technical guidance on fire prevention or control were developed by the Ministry of Housing and Urban Rural Development and the State Administration of Cultural Heritage to protect those well-known historic towns, villages, and buildings in the State Protection List [4,36].

In view of the special value of museums for cultural preservation and tourism, several researchers have suggested improving fire protection safety [6]. Fire protection level on heritage buildings should be prioritized more than ordinary buildings, considering life safety, cultural heritage preservation, and the interest of tourism. However, no reliable and feasible heritage protection legislations tend to be viewed as indirect causes. Present rules and regulations in the form of prescriptive provisions of building codes are formulated for present buildings and are usually based on generalized information of building class (or category) [7]. Heritage buildings may not be designated as a class on their own in most building codes. Thus, inevitable conflict exists between heritage preservation and fire protection provision of building codes. For example, passive fire protection measures frequently involve alterations of building structure or components, which

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are not suitable for historic building preservation because of its heritage values and special building style. Generally, these measures may have a detrimental effect on the special characteristics of heritage buildings.

Heritage villages are usually composed of a group of buildings; however, each heritage village is unique. Each heritage village requires rules and creative solutions on fire protection issues. Generally, the broad safety objectives of building fire protection are life safety, fire prevention, and property protection. Significant attention is provided on adequate property protection without sacrificing life safety when fire disasters occur in valuable historic buildings [8]. As such, performance-based fire safety designs are frequently used as the acceptable approach for heritage building fire protection [9–11]. In performance-based approach, fire safety design is based on engineering principles with quantitative verification methods [12]. Design solutions, which are different to the prescriptive provisions of building codes, can be accepted considering that they can be demonstrated to comply with the performance requirements of the codes. Fire safety engineering design and risk assessment rely on quantified information or data for performance evaluations.

1.2. Research purpose and objectives

In view of performance-based design for heritage village on fire protection, specific building information and quantified parameters should fill the knowledge gaps between the prescriptive building codes and performance-based design concept. The objective of this study is to identify fire hazards and conduct a basic fire safety assessment on a heritage village. This study aims to provide actual information on fire safety problems in heritage villages, especially those timber structural heritage buildings, and to urge developing appropriate policies, design solutions, techniques, and maintenance procedures for heritage building fire protection. To achieve the objectives, a rural village that represents a siheyuan building complex and architectural style is selected for field survey.

1.3. Previous studies of this research

Among the various risk factors that threaten the sustainability of architectural heritage sites, fire hazard can cause the most destructive effects [13]. Fire hazards may be presented in many forms except the fire flames in heritage buildings. Other fire hazards may include ignition sources, fuel loads, and ventilation conditions, as well as defects in evacuation routes [12]. In a survey study on a heritage housing stock in Sydney, structural fire hazards are defined as building structural features that do not comply with the contemporary building regulations [14]. In terms of non-compliances to building regulations, structural fire hazards are digitized and then subjected for statistical analysis to obtain probability estimates of occurrence under various conditions [15,16]. For timber-framed buildings, fire load contents also enhance the risk of fire deflagration. Laranjeira conducted a research on treatment measurement on timber structures and claimed that the usual approach to improve the reaction of existing timber structures to fire is to treat wood with fire retardants [17]. However, such treatment may cause some side effects on the historic buildings.

Vulnerability of fire hazards assessment has been suggested to ensure the permanent and safe existence of heritage assets [18]. The concept of vulnerability has emerged across various disciplines, ranging from engineering to psychology, and its definition varies accordingly. Vulnerability is determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards. It is described as a dynamic and inner feature that is specific to any system [19]. Vulnerability usually indicates the potential for loss, which is relative to event intensity. It becomes visible during a disaster and can be used as the central predictive variable in risk analysis [20,21]. Vulnerability can be assessed from a set of dimensions or parameters, such as building type and environmental conditions [22]. Vulnerability assessment on fire safety in heritage villages is a synthetic process, and various factors may have interrelations, such as buildings structural deterioration and neglectful in taking precautions. An ongoing process with a goal can achieve and support a certain level of fire safety in heritage villages. In historic buildings, performance-based design for fire safety tends to solve the physical problem [23,24].

Risk assessment is the first step in fire protection management. A disaster risk assessment is conducted in terms of cultural heritage disaster mitigation in historic cities to provide a draft proposal with possible disaster mitigation [25]. Fire hazard risk can be evaluated by the scalar product of parameter weights and grades. A single-evaluated value represents the fire safety level provided in a building [26,27]. From macro and micro perspectives, risk analysis on fire spreading between properties is produced with basic documentation in relation to future disaster-prevention measures for cultural heritage properties [16].

2. Research methodology

2.1. Fire hazard factor identification

Fire hazards are usually regarded as the factors that cause ignition and accelerate the spread and/or exacerbate the consequences of fire damages. They may be related to environment, building structures, and building content, as well as human activities. In the current study, fire hazards are defined as (i) the features that do not comply with the contemporary building regulations for fire safety; (ii) flaws and deteriorations in fire safety measures; and (iii) factors that can increase the potential of the ignition and spread of fire.

Site survey was conducted for data collection to identify the fire hazard factors in the heritage village. The main survey points were the structure condition of the surrounding buildings and courtyards and the access layout in the heritage village.

Structural stability and integrity are crucial factors for heritage building survival. In ancient design concept, several brick walls in the courtyards also served as fire barriers in case of fire disasters. The flaws and damages in brick walls are regarded as a fire hazard factor.

Wood or timber elements in buildings are considered fuel load in fire safety engineering. Wood columns and beams in heritage villages are also bearing elements. Their present conditions are crucial to fire safety and structural stability. When exposed to extreme heat, wood will undergo pyrolysis and charring process. The fire-resistive characteristics of exposed wood members are due to the insulated characteristics of the char layer [28,29]. Wood charring rate is affected by four factors, namely, dry density, moisture content, lignin content, and char contraction [28]. The formed cracks in timber structure affect the heat and mass transfer between the flame and the solid [30,31]. Wood carbonization and charring rate are related with moisture content. A detailed survey was conducted on timber columns with the survey on general conditions and data collection of surface moisture content.

Accesses are regarded as active means of fire protection for fire trucks, fire detection, and suppression/extinguishing devices in populated districts. The assurance of accessibility and ready-to-operate condition will aid in alleviating fire danger to buildings and building occupants. Accessibility for fire services is an important measure in modern building fire safety and is explicitly regulated in building codes [7]. Many building codes prescribe minimum distances between buildings as a measure to limit radiant heat flux and minimize the chance of fire spread between buildings [4,7]. Roads also serve as separation buffer zones between buildings. The passage and widths of lanes in the Old Village were assessed to determine accessibility.

Several other fire hazard factors were also identified during the site survey. They may incur fire hazard for its disorder management, or they may be the neglect of necessary precautions against fire hazard.

Therefore, the study on identified fire hazard factors focused on the