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Fire Protection Strategies and Technologies for Heritage Buildings: Experiences from Guangzhou

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Abstract

As the core carrier of Lingnan culture and a nationally famous historical & cultural city, Guangzhou preserves more than 3000 immovable historic buildings, including arcade rows, ancestral halls, Xiguan mansions and modern public edifices. Their brick-timber hybrid structures, high-density "bamboo-tube" street pattern and hot-humid subtropical climate create unique fire challenges. This study systematically summarizes an "inherent-acquired-environmental" superimposed fire-risk mechanism. By integrating traditional Cantonese fire-resistance wisdom—such as Qingyun fire lanes, wok-ear gables and courtyard smoke vents—and heritage-friendly innovations, a three-level policy-technology-management protection framework is established. Hierarchical protection aligned with value grading, life-cycle technology pathways and multi-stakeholder collaboration is proposed. The "minimum-intervention and performance-based" route and the "regulation-guideline-standard" policy loop developed by Guangzhou reduce the fire incidence of priority historic buildings while retaining heritage authenticity, offering a replicable paradigm for balancing fire safety and conservation in hot-humid, high-density contexts.

Keywords

Lingnan-Style Historic Buildings, Performance-Based Fire Safety, Heritage-Friendly Technology, Hot-Humid Climate, Whole-Life-Cycle Management

1. Introduction

1.1. Research Background and Significance

Since its establishment as an administrative division in the Qin Dynasty, Guangzhou, as the starting point of the Maritime Silk Road, has accumulated a rich reserve of architectural heritage. As of January 2025, Guangzhou has announced the 8th batch of historic building lists [1], covering more than 1200 buildings of various types such as modern residential buildings on Zhengnan Road in Yuexiu District, arcade clusters in Liwan District, and the Crystal Palace Boat Hall in Panyu District, forming a heritage pattern characterized by "diversified integration, complete types, and dense distribution". These buildings not only carry the memory of Guangfu culture but also exhibit distinct regional technical features: the "three-bay and two-corridor" layout of Xiguan mansions adapts to the humid-heat climate of Lingnan; the corridor space of arcade buildings balances commercial functions with sunshade and rainproof needs; the purlin-beam wooden frames of ancestral halls demonstrate the craftsmanship of artisans; and the Shameen Island building complex witnesses the exchange between Chinese and foreign architectural cultures.

With the advancement of Guangzhou's "Old City Vitalization" strategy, the adaptive reuse of historic buildings has become a key path for urban renewal. Projects such as the Yongqingfang renovation and the Xingepu Area renewal have transformed numerous historic buildings into mixed-function spaces for commerce, cultural tourism, and residence. However, the functional transformation has led to a significant increase in electricity load, a rise in population density, and the accumulation of combustible loads, all of which have significantly intensified fire risks. From January to February 2025, 7 fire incidents caused by leftover ignition sources occurred in Liwan District alone, 4 of which involved historic residential buildings, with a combustion rate 3 times faster than that of ordinary buildings, highlighting the urgency of fire protection for Guangzhou historic buildings [2].

Fire protection of historic buildings has always faced the core contradiction between "heritage protection" and "safety guarantee": overemphasizing fire safety may damage the authenticity of buildings, while one-sided pursuit of heritage protection may leave major safety hazards. International heritage fire incidents such as the Notre-Dame de Paris (2019) and the National Museum of Brazil (2018), as well as domestic historic building fire cases, all warn that historic buildings lacking a scientific protection system are vulnerable to catastrophic damage in the modern social environment.

The particularity of Guangzhou lies in the triple superimposed challenges faced by its historic buildings: First, inherent defects of the building itself—83% of late Qing Dynasty buildings have decayed timber components, with the fire resistance limit reduced from 0.5 h to less than 0.2 h; Second, the impact of climatic environment—with an average of 80 - 100 thunderstorm days annually, the probability of lightning strikes on buildings without lightning protection devices is 3 times that of modern buildings; Third, constraints of spatial layout—the dense "bamboo tube house" layout results in more than 60% of buildings having a fire separation distance of less than 3 m. Therefore, systematic analyses on fire protection strategies and technologies for Guangzhou historic buildings not only address the practical issues of local heritage protection but also provide a theoretical paradigm and technical reference for fire protection of historic buildings in humid-heat regions and high-density urban areas, with important academic and practical significance.

1.2. Literature Review

A mature "regulation guidance-technical innovation-management collaboration" system has been formed for fire protection of historic buildings. The NFPA 914: Standard for Fire Protection of Historic Structures (National Fire Protection Association, USA) [3] establishes two core principles of "minimum intervention" and "performance-based design", allowing the use of non-traditional fire protection measures on the premise of meeting safety goals. Its 2021 revised version further refines the flame-retardant treatment standards for timber heritage structures. Europe focuses on the integration of traditional structures and modern technologies [4]: the Uffizi Gallery in Florence adopts a "concealed sprinkler + thermal imaging monitoring" system to achieve early fire warning while protecting Renaissance murals; France introduced an AI fire prediction model in the post-fire restoration of Notre-Dame de Paris, combining laser scanning data to construct a digital twin of fire spread [5] [6].

Asian countries have conducted specialized research on fire protection of timber structures [7]: the Nara National Research Institute for Cultural Properties (Japan) has developed a nano-silica flame retardant, which can increase the fire resistance limit of wood by 1.2 times without affecting air permeability; Gyeongju Bulguksa Temple (South Korea) adopts a composite technology of "flame retardant coating + inert gas fire suppression", successfully solving the fire protection problem of timber pagodas. The Guidelines for Fire Protection of Historic Buildings [8] emphasize that fire protection measures should be dynamically matched with the results of building historical value assessment, providing methodological guidance for global heritage fire protection.

In China, research on the fire protection of ancient buildings primarily focuses on two directions [9]-[11]: technological improvement and policy adaptation. In terms of technology, the research team of Tsinghua University revealed the formation mechanism of the "chimney effect" in historic buildings through PyroSim simulation and proposed a smoke exhaust optimization scheme based on smoke layer control; a study on fire dynamics simulation of Guangfu ancestral halls by South China University of Technology team showed that for every 0.5 m increase in the height of gable ridges, the probability of horizontal fire spread decreases by 40%. In terms of policies, the Technical Standard for restoration and reinforcement of historic buildings issued by Guangdong Province [12] puts forward regional requirements for typhoon flying fire prevention, moisture prevention, and corrosion prevention. As a pioneer pilot city, Guangzhou implemented China's first local standard Technical specification for fire protection of existing historical building (DB4401/T 109-2021) in 2021 [13], initiating the "structure reinforcement first, then fire protection" implementation process, which provides an operational basis for fire protection transformation of historic buildings.

1.3. Limitations of Existing Research and Research Focus

Although existing research has laid a certain foundation, there are still three limitations: first, insufficient regional adaptability—there are few specialized studies on unique issues in Guangzhou such as accelerated decay of timber components under humid-heat climate and spread of typhoon flying fire; second, inadequate technology integration—the integration of traditional fire protection wisdom and modern technologies mostly remains at the single-point application level, lacking systematic design; third, weak research on management mechanisms—insufficient discussion on the responsibility division and collaboration mechanism among "government-property owners-users" in adaptive reuse.

Taking Guangzhou historic buildings as the research object, this study addresses three key issues based on local specifications and empirical data: first, analyzing the formation mechanism of fire risks in historic buildings in high-density urban areas of humid-heat regions; specifically, the "inherent-acquired-environmental" superimposed fire risk mechanism refers to the fire risks of Guangzhou historic buildings resulting from the superposition of three aspects: inherent material defects of the buildings themselves (inherent), increased load caused by functional transformation (acquired), and natural conditions such as humid and hot climate (environmental); second, establishing an integrated fire protection technology system combining "traditional wisdom and modern technologies"; third, proposing a whole-life-cycle management strategy adapted to adaptive reuse, and systematically refining the replicable "Guangzhou experience".

Herein, the "Guangzhou Experience" is defined as a replicable model that integrates a three-level policy framework, the integration of traditional wisdom and modern technologies, and a whole-life-cycle management system.

2. Type Characteristics and Fire Risk Mechanism of Guangzhou Historic Buildings

2.1. Building Type Classification and Regional Characteristics

2.1.1. Building Type System and Distribution Characteristics

Based on the Planning for the Protection and Utilization of Guangzhou historic Buildings and data from the 8th batch of historic building lists, Guangzhou historic buildings can be divided into six categories, with significant regional differences in their distribution and characteristics (Figure 1 and Table 1).

In terms of distribution, Yuexiu District and Liwan District concentrate 62% of historic buildings, forming a high-density contiguous distribution pattern. For example, the distance between arcade buildings on Beijing Road is generally less than 2 m, and "bamboo tube houses" in the Xiguan area are densely arranged, creating conditions for fire spread.

Figure 1. Guangzhou historic buildings.

Table 1. Main types and distribution characteristics of Guangzhou historic buildings.

Building Type	Typical Example	Distribution Area	Structural Characteristics	Core Value Elements
Arcade Buildings	Arcades at 187-193 Danan Road	Liwan District, Yuexiu District	Brick-concrete ground floor + timber upper floor, corridor layout	Arcade columns, parapet decorations, and cast iron railings
Ancestral Halls	Chen Clan Ancestral Hall	Liwan District, Panyu District	Purlin-beam wooden frame, multi-courtyard layout	Wood carving, brick carving, stone carving decorations, courtyard pattern
Xiguan Mansions	Residential Building at 2 Qiming 1st Road	Xiguan, Liwan District	Brick-timber mixed structure, three-bay and two-corridor layout	Manchurian windows, sliding latticed doors, Qingyun lanes
Modern Government Buildings	Former Site of Civilian Palace	Yuexiu District	Brick-concrete structure, Chinese-Western integrated style	Arch windows, gable walls, column decorations
Villa Buildings	Ou Fangpu Villa	Conghua District	Brick-timber or stone-timber mixed structure, sloped roof	Column structure, roof shape, and garden environment
Industrial Heritage	Former Site of Xietonghe Machinery Factory	Haizhu District	Reinforced concrete frame + steel roof truss	Workshop space, machinery and equipment, chimneys

2.1.2. Regional Architectural Technical Characteristics

The technical characteristics of Guangzhou's historic buildings are highly adapted to the Lingnan climate but also bring unique fire protection challenges:

1) Spatial Design for Ventilation and Moisture Prevention: The small court-

yards and deep corridors of Xiguan mansions, as well as the transparent column corridors of arcade buildings, can achieve natural ventilation and cooling, but they easily form a "chimney effect" during fires, leading to a vertical smoke spread speed of 2 - 3 m/s;

2) Material Selection Based on Local Resources: Chinese fir and pine are used as main load-bearing components, and their moisture content decreases to 10% - 15% after long-term aging, requiring only 5 - 10 J of ignition energy to sustain combustion within 1 minute when exposed to open flames;

3) Structural Treatment Adapting to Climate: The design of thin walls and large windows improves lighting and ventilation performance, but results in a fire resistance limit of exterior walls generally lower than 0.5 h, which cannot effectively block flame spread.

2.2. Multi-Dimensional Formation Mechanism of Fire Risks

2.2.1. Innate Defects of the Building Itself

1) Flammability of the Structural System: 83% of late Qing Dynasty and early Republic of China buildings adopt brick-timber mixed structures, with timber columns, beams, and rafters accounting for 35% - 50% of the total components, without fire protection treatment. Surveys show that 72% of historic buildings in Liwan District have varying degrees of decay in timber components, with the fire resistance limit reduced from the original design of 0.5 h to less than 0.2 h, and some severely decayed components collapse immediately when exposed to fire.

2) Restrictions of Spatial Layout: In old urban areas such as Beijing Road Street in Yuexiu District, more than 60% of buildings have a fire separation distance of less than 3 m, failing to meet the minimum requirement of 3.5 m in GB 50016 Code for Fire Protection Design of Buildings. Although Qingyun lanes are retained as traditional fire separation facilities in some areas, their width has narrowed from the original 1.5 m to 0.8 - 1.0 m, reducing fire protection efficiency by more than 50%.

3) Lack of Facilities Configuration: 90% of municipal-level historic buildings are not equipped with indoor fire hydrants, and 75% lack automatic alarm systems. Due to the distance from municipal water supply networks, the fire water source guarantee rate of villa buildings in Wenquan Town, Conghua District is only 30%, and initial firefighting completely relies on manual fire extinguishing. (**Figure 2**)

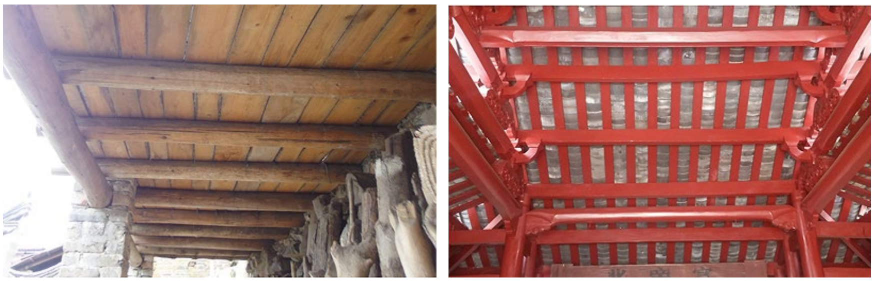

Figure 2. Timber components of Guangzhou's traditional historical architecture.

2.2.2. Acquired Risk Superposition from Utilization

1) Load Surge from Functional Transformation: In adaptive reuse projects such as Yongqingfang, 38% of historic buildings have been transformed from residential to catering or homestay functions, with electricity load increasing from the original 2 - 3 kW to 15 - 20 kW. However, the cross-section of the original power distribution lines is only 2.5 mm^2, and overloaded operation causes the line temperature to reach above 160˚C, accelerating the aging of insulation layers by 3 times.

2) Structural Damage from Spatial Transformation: 45% of users have unauthorized construction behaviors, using flammable materials such as wood boards and foam boards to partition spaces. For example, an additional mezzanine was added to store debris in the residential building at 27 Xianji West Road, Liwan District, increasing the combustible load by 200 kg/m^2, which far exceeds the specification limit.

3) Human Hazards from Usage Management: Fire cases in Liwan District in 2025 show that 6 fires were caused by leftover ignition sources (incense burning, mosquito coils, cigarette butts), accounting for 85.7%. Ancestral halls with frequent sacrificial activities hold more than 100 incense-burning ceremonies annually, and 70% of them do not have dedicated fire-protected sacrificial areas. (**Figure 3**)

Figure 3. Evacuation routes are blocked.

2.2.3. Environment-Induced Effects of Natural Conditions

1) Material Deterioration from Humid-Heat Climate: Guangzhou has an average annual relative humidity of 77%, and the high-temperature and high-humidity environment in summer accelerates the decay of timber components and the aging of electrical lines, increasing the probability of line short-circuit faults by 2.5 times compared to dry regions. At the same time, the moisture content of wood fluctuates greatly with seasons (12% - 22%), and it is prone to an extremely flammable state in dry seasons.

2) Disaster Coupling from Typhoons and Thunderstorms: With an average of 80 - 100 thunderstorm days annually, 40% of historic buildings are not equipped with lightning protection devices, and the probability of lightning strikes is 3 times that of modern buildings. During typhoon seasons, winds above 4 m/s can cause

flying fire from roofs to spread over 50 m, posing a risk of contiguous combustion to island building clusters such as Shameen Island.

3) Risk Amplification from High-Temperature Weather: There are an average of 35 days with temperatures above 35˚C in summer, reducing the auto-ignition point of combustible materials by 10% - 15% and decreasing the heat dissipation efficiency of electrical equipment by 30%, increasing the fire probability by 60% compared to other seasons.

2.3. Differentiated Risk Characteristics of Different Building Types

2.3.1. Residential Buildings: Electrical Hazards and Evacuation Difficulties

Represented by Xiguan mansions and ordinary residential buildings, accounting for 42% of the total number of historic buildings. Core risk points include: first, aging electrical lines and unauthorized wire connection—65% of insulation layers of buildings are damaged due to over 50 years of use; second, narrow evacuation channels—90% of residential buildings have an evacuation width of less than 0.9 m, and 58% of them are occupied by debris; third, mixed functions—the "front shop, back residence" model interleaves commercial and residential electricity use, highlighting the risk of overloading. This type of building accounts for 62% of fire incidents in Guangzhou's historic buildings. (**Figure 4**)

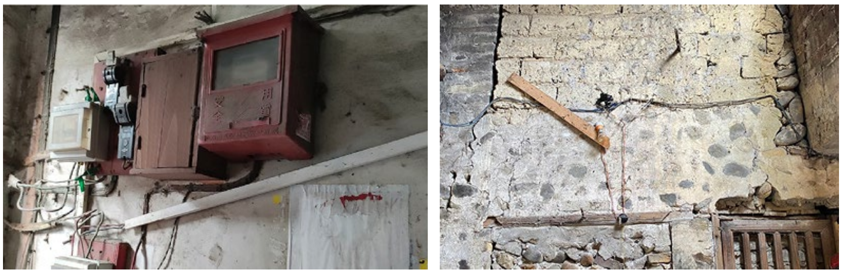

Figure 4. Electrical hazard.

2.3.2. Commercial Buildings: Dense Loads and Fire Fighting Difficulties

Represented by arcade commercial streets, accounting for 28% of the total. Main risks include: first, high combustible loads—the stacking density of goods in arcade shops on Shangxiajiu Road reaches 150 kg/m^2, mostly flammable materials such as textiles and paper; second, blocked evacuation—35% of arcade corridors are occupied by goods, with a passage width of less than 1.2 m; third, difficult fire fighting—the timber arcade floors above the corridors are prone to three-dimensional combustion, and the range of water guns is difficult to cover. In a 2025 fire at a grilled fish restaurant in Liwan District, although the combustion area was only 2 m^2, it took less than 2 minutes to spread to the arcade corridor.

2.3.3. Ancestral Halls: Concentrated Ignition Sources and Rapid Spread

Accounting for 15% of the total, with Chen Clan Ancestral Hall as a typical example. Risk characteristics are manifested as: first, normalized incense-burning ignition sources—80% of ancestral halls do not have fire-protected sacrificial areas, leading to a high probability of incense ash ignition; second, dense timber components—the distance between timber components in purlin-beam frames is only 0.3 - 0.5 m, with a horizontal fire spread speed of 0.6 - 0.8 m/s; third, difficult smoke exhaust in high spaces—the clear height of halls exceeds 8 m, the stable time of smoke layers is short, and the visibility for personnel evacuation decreases rapidly.

2.3.4. Industrial Heritage: Open Structures and Flying Fire Risks

Accounting for 10% of the total, such as the former site of Xietonghe Machinery Factory. Risk points include: first, difficult fire control in large spaces—the span of workshops reaches 15 - 20 m, with a wide range of fire thermal radiation; second, easy failure of metal components—the fire resistance limit of steel roof trusses is only 0.25 h, which deforms within 15 minutes under high temperatures; third, hazardous residues—some industrial heritage retains dangerous goods such as oil barrels and chemicals, increasing the risk of explosion.

3. Construction and Innovation of the Fire Protection Policy System for Guangzhou Historic Buildings

3.1. Evolution Logic of the Policy System

3.1.1. Embryonic Stage (2000-2010): Basic Protection and Preliminary Specifications

This stage focused on cultural heritage buildings as the core protection objects, with policies emphasizing the prohibition of destructive construction. The Regulations on the Protection of Guangzhou as a National Historic and Cultural City first incorporated "fire protection facility construction" into the protection responsibilities of historic buildings, but did not specify specific standards. In 2007, with reference to Order No. 61 of the Ministry of Public Security Administrative Regulations on Fire Safety of Institutions, Organizations, Enterprises, and Institutions, a fire safety responsible person system for historic buildings was established, but lacked targeted technical guidance. In practice, it often fell into the dilemma of "either over-transformation or ignoring risks".

3.1.2. Development Stage (2011-2020): Technical Guidance and Pilot Exploration

As Guangzhou became a national pilot city for the protection and utilization of historic buildings, the policy system moved towards technicalization and refinement. The Planning for the Protection and Utilization of Guangzhou Historic Buildings compiled by South China University of Technology in 2016 first clarified the core value elements of historic buildings, delineating "untouchable" red lines for fire protection transformation. The Guidelines for Structural Safety and Reinforcement of Guangzhou historic Buildings proposed the principle of "structure reinforcement first, then fire protection", requiring that fire protection transformation must be based on structural safety to avoid secondary damage to the building itself. During this stage, fire protection pilot transformations were completed in 12 areas including Yongqingfang Phase I and Shameen Island, accumulating preliminary practical experience.

3.1.3. Mature Stage (2021-Present): Standard Improvement and System Formation

The implementation of Technical Specification for fire protection of existing historical building in 2021 marked the formation of China's first local standard system for fire protection of historic buildings. This specification connects national standards such as GB 50016 and makes 12 adaptive adjustments for the particularities of historic buildings. For example, the fire separation distance in core protection areas can be implemented at 70% of the national standard (but supporting active fire protection measures are required), forming a closed-loop system of "safety judgment-hazard inspection-measure implementation-acceptance management".

3.2. Core Framework and Content of the Policy System

3.2.1. "Three-Tier and Three-Category" Policy Hierarchy

Guangzhou has established a "regulation-guideline-specification" three-tier policy framework, covering the entire process of "planning-design-implementation-management" (Table 2).

Table 2. Framework of the fire protection policy system for Guangzhou historic buildings.

Policy Tier	Core Document	Release Time	Main Content	Positioning
Legal Layer	Regulations on the Protection of Guangzhou as a National Historic and Cultural City	2021 (Revised)	Clarifying fire protection responsibilities and planning requirements	Legal Basis
Guidance Layer	Strategy and Technical Guidance for Improving Fire Protection Performance of Historic Buildings	2025	Hazard inspection, measure selection, process management	Operational Guide
Specification Layer	Technical specification for fire protection of existing historical building (DB4401/T 109-2021)	2021	Design standards, construction requirements, and acceptance specifications	Technical Standard

Meanwhile, differentiated requirements are formulated for three types of protection objects: cultural heritage buildings, historic buildings, and traditional style buildings: cultural heritage buildings strictly follow the "minimum intervention" principle, allowing only concealed fire protection facilities; historic buildings can adopt performance-based design appropriately; traditional style buildings can be equipped with facilities in accordance with modern building standards under the premise of style coordination.

3.2.2. Four Core Policy Innovations

1) Value-Prioritized Evaluation Mechanism: All fire protection transformation projects are required to first conduct a value element evaluation to clarify which components (such as Manchurian windows and wood carvings) are "absolute protection items" with no transformation allowed, and which are "adjustable items" that can adopt concealed measures. The evaluation results must be reviewed and approved by the cultural heritage expert committee before implementation.

2) Performance-Based Exemption System: For projects that cannot meet the requirements of GB 50016 due to historic style restrictions, an application for a performance-based design exemption can be submitted. It is necessary to prove through fire dynamics simulation that the fire risk is lower than the specification requirements. For example, for the insufficient fire separation distance of arcade streets, compensation measures such as adding automatic sprinkler systems and shortening fire detection time can be adopted.

3) Whole-Life-Cycle Management Process: A three-year cycle system of "daily inspection-regular detection-special treatment" is established: users conduct weekly appearance inspections, professional institutions conduct semi-annual thermal imaging detection, and special inspections are carried out after disasters. Detection data is uploaded to the Guangzhou Historic Building Protection Information Platform to realize dynamic supervision.

4) Multi-Department Collaboration Mechanism: A joint meeting system of four departments (housing and urban-rural development, fire rescue, cultural heritage, and planning) is established. Fire protection review must seek the opinions of the cultural heritage department, and cultural heritage restoration plans must meet fire protection requirements to avoid disconnection in approval.

3.3. Comparison and Adaptability with Domestic and International Policies

3.3.1. Connection and Differences with International Standards

Guangzhou's policy system draws deeply on the performance-based concept of NFPA 914 Standard for Fire Protection of Historic Structures, but emphasizes regional adaptability more (**Table 3**).

Table 3. Comparison between Guangzhou Specification and NFPA 914.

Comparison Dimension	Guangzhou DB4401/T 109-2021	NFPA 914 (2021 Edition)	Reason for Differences
Scope of Application	Covering industrial heritage and traditional style buildings	Focusing on cultural heritage buildings and historic buildings	Guangzhou has a large number of industrial heritage requiring special coverage
Climate Consideration	Specifying requirements for typhoon flying fire prevention and moisture prevention	No targeted climate provisions	Adapting to the humid-heat and typhoon-prone climate of Lingnan
Approval Mechanism	Multi-department collaborative approval	Fire department-led approval	Adapting to China's administrative management system
Technical Measures	Recommending activation of traditional structures	Focusing on modern technology applications	Highlighting the inheritance of Guangfu architectural wisdom

Compared with the Venice Charter, Guangzhou's policies further quantify the "minimum intervention" principle into technical indicators, such as requiring the thickness of fire retardant coatings to be no more than 0.5 mm and the concealment rate of fire protection facilities to be over 90%, enhancing operability.

3.3.2. Complementation and Refinement of National Standards

Aiming at the limitations of national standards such as GB 50016 in the application of historic buildings, Guangzhou's policies make three refinements:

1) Adjustment of Fire Separation Distance: The fire separation distance of buildings in core protection areas can be implemented at 70% of the national standard, but must meet the performance indicator of "heat flux ≤ 37 kW/m^2", verified through FDS simulation;

2) Optimization of Evacuation Width: For residential buildings that cannot meet the 1.1 m evacuation width, a "staggered evacuation + emergency lighting enhancement" scheme can be adopted, with the evacuation time controlled within 3 minutes;

3) Guidance on Facility Selection: Clarifying the list of fire protection facilities for different types of buildings, such as recommending high-pressure water mist systems for ancestral halls and simple sprinkler systems for arcades.

These adjustments not only conform to the basic principles of national standards but also solve the practical difficulties of historic buildings, providing a model for the formulation of local standards nationwide.

4. Modern Transformation of Traditional Fire Protection Wisdom in Guangfu Architecture

4.1. Fire Protection Mechanism of Traditional Spatial Layout and Contemporary Application

4.1.1. Fire Separation Efficiency of Street Pattern

The "comb-shaped layout" of old Guangfu urban areas contains a scientific fire protection logic: main streets (3 - 4 m wide) serve as main fire-fighting access, secondary lanes (1.5 - 2.0 m wide) as fire separation, and Qingyun lanes (1.2 - 1.5 m wide) as buffer zones between buildings. Through PyroSim simulation, Qingyun lanes can reduce the incident heat flux of adjacent building exterior walls from 150 kW/m^2 to below 37 kW/m^2, a reduction of 75%, effectively blocking direct flame spread.

In contemporary transformation, Guangzhou adopts the strategy of "retaining lanes and widening roads": for historic streets such as Tiyun East Road in Liwan District, the original width of Qingyun lanes is retained, and occupied debris is cleared to restore their fire protection function; some secondary lanes are widened to 3 m to meet the passage of light fire-fighting vehicles. By sorting out 12 Qingyun lanes on Shameen Island, a "grid-shaped" fire separation system is constructed, reducing the fire spread control range from the original 100 m^2 to 25 m^2.

4.1.2. Fire Spread Prevention of Gable Wall Structures

The fire-proof gable walls (also known as "wok-ear walls") commonly used in

Guangfu ancestral halls and residential buildings have a positive correlation between the height of their vertical ridges and fire protection efficiency. Simulations show that when the vertical ridge height is 1.2 m, it can block 60% of horizontal flames; when the height is increased to 1.8 m, the blocking rate reaches 85%. Meanwhile, the slope design of gable walls can guide smoke to discharge upward, reducing thermal radiation to adjacent buildings.

In restoration projects, Guangzhou strictly follows the principle of "restoring to the original state": the damaged gable walls of Chen Clan Ancestral Hall are restored to the original dimensions, with the vertical ridge height restored to 1.8 m; for modern buildings such as the residential building at 2 Zhengnan Road in Yuexiu District, concealed fire-proof gable walls are added, maintaining the original appearance externally and using fire-resistant bricks internally, with a fire resistance limit of 2.0 h.

4.1.3. Smoke Exhaust and Heat Dissipation of Courtyard Spaces

The courtyards of Xiguan mansions and ancestral halls are not only the core of ventilation and lighting but also natural smoke exhaust facilities. Simulation data shows that a 3 m × 4 m courtyard can extend the time for the smoke layer height in the hall to remain above 2.5 m by 4 times, providing sufficient time for personnel evacuation. Meanwhile, the bluestone slabs on the courtyard ground can form a fire separation zone, preventing fire spread to adjacent rooms.

In modern transformation, Guangzhou adds invisible smoke exhaust skylights around courtyards, which remain closed to maintain the style normally and open automatically during fires, increasing smoke exhaust efficiency by 30%. Through courtyard optimization of a residential building in Yongqingfang, the fire smoke discharge time is shortened from the original 2 minutes to 40 seconds.

4.2. Exploration of Fire Protection Value of Traditional Materials and Techniques

4.2.1. Flame Retardant Properties of Natural Materials

The "tung oil-porcelain clay" composite coating used by Lingnan craftsmen in the Qing Dynasty can increase the fire resistance limit of wood by 40% according to tests. The principle is that tung oil penetrates to form a hydrophobic layer, and porcelain clay forms a glaze-like protective layer at high temperatures, blocking the contact between oxygen and wood. This technique has the advantages of environmental protection and air permeability, avoiding damage to wood caused by modern chemical flame retardants.

Based on this, the Guangzhou Cultural Heritage Protection and Research Institute has developed an improved coating, retaining the core components of tung oil and porcelain clay and adding nano-silica to enhance adhesion. This coating increases the combustion performance of wood from grade B2 to B1, with a coating thickness of only 0.3 mm, which does not affect the appearance of wood grain. This coating has been applied to protect the timber components of the Crystal Palace Boat Hall in Panyu District.

4.2.2. Fire Resistance Advantages of Masonry Structures

The solid brick walls and bluestone slab floors commonly used in Guangfu architecture have excellent fire resistance. Tests show that a 240 mm thick solid brick wall has a fire resistance limit of 1.5 h, and bluestone slab floors can withstand temperatures of 800˚C without cracking. The reinforced concrete columns on the ground floor of arcades (using imported Portland cement in the early days) have a fire resistance limit of over 3.0 h, serving as "safety columns" during fires.

In restoration, Guangzhou adheres to the principle of "using bricks instead of concrete": for damaged walls of arcades on Danan Road, traditional blue bricks are used for repair instead of modern blocks; fire-proof mortar is injected into the interior of walls using high-pressure grouting, increasing the fire resistance limit from 1.5 h to 2.0 h without affecting the appearance.

4.2.3. Anti-Corrosion and Fire Protection Treatment of Bamboo-Timber Components

Traditional Guangfu architecture uses the "smoke fumigation + tung oil soaking" process for bamboo-timber components, achieving both anti-corrosion and fire protection effects. Smoke fumigation forms a carbonized layer on the wood surface, delaying combustion speed when exposed to fire; tung oil penetration forms a protective layer, preventing moisture intrusion and microbial corrosion. The century-old timber beams of Xie Yibang Villa in Conghua District, which used this process, are still well-preserved, with a fire resistance limit of 0.6 h.

In modern transformation, Guangzhou combines this process with chemical treatment: bamboo-timber components are first carbonized by smoke fumigation, then coated with environmentally friendly flame retardants, increasing the fire resistance limit to 1.0 h. This method has been applied to the restoration of 6 villa buildings in Wenquan Town, Conghua District.

4.3. Activation of Fire Protection Functions of Traditional Water Source Systems

4.3.1. Water Storage of Ponds and Wells

The feng shui ponds around Xiguan mansion clusters and courtyard wells are important water sources for traditional fire protection. According to historical records, in the late Qing Dynasty, there was 1 fire-fighting well for every 50 households in the Xiguan area, and the water storage capacity of feng shui ponds exceeded 500 m^3, which could meet the needs of 10 initial fire-fighting operations. These water sources have the advantages of convenient water intake and stable water quality, and are not affected by municipal water supply interruptions.

In the renewal of historic districts, Guangzhou activates the traditional water source system: ancient wells in Lingnan Street, Liwan District are cleaned and restored, equipped with manual water pumps, with a water output flow rate of 10 L/s; some feng shui ponds are transformed into landscape fire-fighting water pools, retaining the original style and adding invisible water intake ports to meet the water intake needs of fire-fighting vehicles.

4.3.2. Water Transmission Network of Open and Hidden Ditches

The open and hidden ditches in traditional Guangfu settlements not only undertake drainage functions but also serve as fire-fighting water transmission channels. Open ditches (0.3 - 0.5 m wide) connect ponds and wells, forming a networked water transmission system. During fires, water can be transported to the fire point using buckets, or temporary ditches can be excavated to expand the water supply range.

In contemporary transformation, Guangzhou has carried out anti-seepage treatment on the open ditches in Hongqiao Street, Yuexiu District, retaining the original stone masonry and adding invisible gates to control water flow. In fire simulation drills, this system can transport firefighting water to the fire point within 100 m in 5 minutes.

5. Modern Technological Innovation and Application for Fire Protection of Guangzhou Historic Buildings

5.1. Heritage-Friendly Detection Technology System

5.1.1. Application of Non-Destructive Detection Technology

Aiming at the characteristics of historic buildings with concealed components and difficulty in disassembly, Guangzhou adopts a "space-ground-interior" three-dimensional detection technology:

1) Space Detection: Unmanned Aerial Vehicles (UAVs) equipped with thermal imagers and high-definition cameras conduct patrol inspections on the roofs of historic buildings on Shameen Island, identifying hidden dangers such as carbonization of timber components and roof leakage. The detection efficiency is 5 times higher than manual detection, and it avoids the disturbance of scaffolding construction to buildings;

2) Ground Detection: Ultrasonic tomography scanners are used to detect internal defects of timber beams in Chen Clan Ancestral Hall, which can identify carbonized layers above 2 mm with a detection depth of 0.5 m;

3) Interior Detection: Endoscopes are used to detect internal cavities and line aging in walls. During the detection of the former site of Huilai Hotel in Liwan District, 3 concealed electrical hazards were found.

The application of these technologies has increased the hidden danger detection rate of historic buildings from the original 45% to 92%, with the disturbance rate to buildings during detection below 1%.

5.1.2. Integration of Environmental Monitoring Technology

Guangzhou has developed a "historic Building Microenvironment Monitoring System", integrating 12 types of sensors for temperature, humidity, moisture content, and smoke concentration, to implement 24-hour monitoring of key buildings:

1) Moisture Content Monitoring of Timber Components: Automatic alarms are triggered when the moisture content is below 12% (extremely flammable state), and the spray system is linked to increase humidity appropriately;

2) Electrical Parameter Monitoring: Real-time collection of current and temperature of power distribution lines, with automatic power cutoff when overloaded;

3) Wind Environment Monitoring: Flying fire warnings are issued when the wind speed exceeds 4 m/s, and the roof fire water curtain system is activated.

This system has been applied to 15 national key cultural heritage protection units, with a fire hazard early warning accuracy of 98% and an average advance warning time of 15 minutes.

5.2. Fire Protection Enhancement Technology for Building Bodies

5.2.1. Flame Retardant Treatment Technology for Timber Components

Differentiated treatment schemes are adopted for timber components of different value levels in Guangzhou:

1) Core Protection Components (such as wood carvings in Chen Clan Ancestral Hall): Vacuum penetration treatment with nano-silica-based flame retardants, with a penetration depth of 3 - 5 mm, increasing the combustion performance from grade B2 to B1 without affecting the air permeability and grain of wood;

2) Load-Bearing Timber Components (such as beams and rafters): Composite protection of "flame retardant coating + metal sheath", using transparent fluorocarbon resin-based materials for the coating with a thickness ≤ 0.5 mm, and the metal sheath is concealed inside the components, increasing the fire resistance limit to 0.8 h;

3) Ordinary Timber Components (such as doors and windows): Coating with improved tung oil-porcelain clay coatings to achieve both flame retardant and anti-corrosion functions.

Tests show that after treatment, the combustion speed of timber components is reduced by 60% at a high temperature of 700˚C, and the carbonization depth is controlled within 5 mm.

5.2.2. Fire Protection Transformation of Walls and Roofs

1) Wall Transformation: Under the premise of maintaining the appearance of solid brick walls, inorganic fire-proof mortar (mainly composed of magnesium hydroxide) is injected into the interior using high-pressure grouting, increasing the fire resistance limit from 1.5 h to 2.0 h, with a decrease in compressive strength of no more than 10%. This technology has been applied to the transformation of arcade clusters on Danan Road, Yuexiu District, with a total treated wall area of 23,000 m^2;

2) Roof Protection: A 0.3 mm thick titanium-zinc alloy thin plate is added under the traditional tile roof, which can effectively block sparks from igniting timber rafters, with a weight of only 0.8 kg/m^2, not increasing the roof load. After 5 historic buildings on Shameen Island adopted this technology, the roof fire protection rate reached 100%;

3) Floor Reinforcement: Timber floors are treated with composite "fire-proof plywood + steel wire mesh", using flame-retardant plywood for the fire-proof

layer, and the steel wire mesh is concealed under the surface layer, increasing the fire resistance limit from 0.25 h to 0.75 h.

5.2.3. Concealed Installation of Fire Separation

To solve the problem of difficulty in setting up solid fire walls in historic buildings, Guangzhou has developed three types of concealed fire separation technologies:

1) Concealed Fire Curtains: Normally stored in the ceiling, automatically descending during fires, with the curtain surface using decorative materials consistent with the wall, achieving a concealment rate of 95%;

2) Fire-Proof Sealants: Intumescent fire-proof sealants are filled in door and window gaps and pipeline penetrations, which expand 10 times when exposed to fire to form a seal, with a fire resistance limit of 1.5 h;

3) Smoke Barriers: Made of transparent tempered glass, installed under the ceiling without affecting the spatial visual effect, and can effectively control the spread range of smoke.

5.3. Adaptive Configuration Technology of Fire Protection Facilities

5.3.1. Miniaturization and Concealment of Fire Suppression Systems

Aiming at the characteristics of historic buildings with small spaces and sensitive styles, Guangzhou adopts three types of adaptive fire suppression systems:

1) High-Pressure Water Mist Systems: With a water consumption of only 1/10 of traditional sprinkler systems and a spray particle size ≤ 100 μm, they can reduce secondary damage to wood carvings and color paintings while extinguishing fires. Concealed nozzles are used in ancestral halls, embedded in brackets or caissons, with an invisible appearance;

2) Inert Gas Fire Suppression Systems: Installed in enclosed spaces such as cultural relic exhibition rooms, with a fire suppression concentration controlled below 45% to avoid chemical damage to paper and textile cultural relics, and a response time ≤ 10 s;

3) Portable Water-Based Fire Extinguishers: Configured for residential historic buildings, with a fire extinguishing efficiency 30% higher than dry powder fire extinguishers, and environmentally friendly, suitable for fire fighting of timber components.

5.3.2. Wireless and Intelligent Alarm Systems

Guangzhou fully promotes wireless fire alarm systems to avoid damage to building structures caused by line laying:

1) Wireless Smoke Detectors: Using LoRa IoT technology for signal transmission, with a battery life of 5 years, achieving a coverage rate of 98% in the Xingepu Area transformation, with a false alarm rate below 1%;

2) Aspirating Smoke Detectors: Used in high spaces (such as ancestral halls), collecting air samples through pipelines, which can issue warnings when the smoke concentration is only 0.05% obs/m, 60 seconds earlier than traditional de-

tectors;

3) Intelligent Emergency Lighting: Using LED light sources, with an appearance imitating traditional oil lamps, automatically switching to emergency mode during fires to indicate evacuation routes.

5.3.3. Diversified Guarantee of Fire Water Sources

Aiming at the problem of insufficient municipal water supply for historic buildings, Guangzhou has built a "multi-source complementary" fire water source system:

1) Activation of Traditional Water Sources: Transforming ancient wells into fire water sources, equipped with submersible pumps and pressure stabilizing equipment to ensure a fire hydrant outlet pressure ≥ 0.25 MPa;

2) Miniature Fire Water Pools: Setting up concealed pools with a capacity of 5 - 10 m^3 in building courtyards or basements, disguised as landscape facilities externally;

3) Mobile Fire Water Sources: Equipping contiguous historic districts with small fire-fighting water tankers, with a water storage capacity of 2 m^3, which can quickly reach the fire point through Qingyun lanes.

This system has increased the fire water source guarantee rate of historic buildings from the original 58% to 95%.

5.4. Smart Fire Protection Management Technology Platform

The Smart Fire Protection Management Technology Platform is a fully implemented municipal system in Guangzhou, integrating sensor data from 236 historic buildings, rather than a conceptual model.

5.4.1. Monitoring and Early Warning Module

Integrating sensor data from smoke detectors, temperature sensors, and electrical fire monitors, a "perception-transmission-judgment" integrated monitoring network is built:

1) Data Collection: Sensors collect data at a frequency of 1 time per minute, transmitted to the municipal platform via 5G network;

2) Intelligent Judgment: Based on the PyroSim simulation database, a fire spread prediction model is established, which can predict the fire development path and impact range within 30 seconds after inputting real-time wind speed, component moisture content, and other parameters;

3) Hierarchical Warning: Setting up three-level warnings (blue, yellow, red) corresponding to hidden dangers, dangers, and fire states, respectively, linking SMS and APP to push early warning information.

5.4.2. Emergency Response Module

The platform integrates "plan-dispatching-disposal" functions:

1) Plan Management: Storing 120 special emergency plans for different types of buildings, including 3D building models, evacuation routes, and water source lo-

cations;

2) Intelligent Dispatching: Automatically matching the nearest miniature fire station and fire water source when a fire occurs, generating the optimal disposal route;

3) Remote Control: Remotely activating smoke exhaust skylights, fire suppression systems, and other equipment to achieve remote disposal of initial fires.

5.4.3. Daily Management Module

Realizing full-process digital management of fire protection work:

1) Inspection Management: Using mobile APPs to record inspection situations, automatically generating hidden danger rectification ledgers, and automatically reminding of overdue rectification;

2) Maintenance Management: Tracking maintenance records of fire protection facilities, automatically generating maintenance tasks when due;

3) Data Statistics: Analyzing the distribution law of fire hazards to provide data support for policy formulation.

This platform has been connected to 236 key historic buildings in Guangzhou, shortening the fire response time from the original 8 minutes to 3 minutes, and increasing the initial fire control rate to 85%.

6. Whole-Life-Cycle Fire Protection Strategy System for Guangzhou Historic Buildings

6.1. Hierarchical and Zoned Preventive Protection Strategy

6.1.1. Hierarchical Protection Standards Based on Value Levels

According to the Guangzhou Historic Building Protection List, historic buildings are divided into three levels of protection, corresponding to differentiated fire protection measures (Table 4).

Table 4. Hierarchical protection standards for Guangzhou historic buildings.

Protection Level	Protection Objects	Core Protection Requirements	Fire Protection Facility Configuration
Level 1	National key cultural heritage protection units (e.g., Chen Clan Ancestral Hall)	Fire resistance limit increased to above 1.0 h, and fire spread controlled within a single area	Aspirating smoke detectors + inert gas fire suppression systems
Level 2	Provincial cultural heritage protection units (e.g., Jinlun Guild Hall)	Fire resistance limit increased to above 0.8 h, and fire spread controlled within the building	Wireless smoke detectors + high-pressure water mist systems
Level 3	Municipal-level historic buildings (e.g., ordinary arcades)	Fire resistance limit increased to above 0.5 h, with initial firefighting capability	Independent smoke detectors + simple sprinklers + fire extinguishers

The core of hierarchical protection is "matching value with safety", avoiding heritage damage and resource waste caused by over-protection.

6.1.2. Zoned Fire Protection System Based on Spatial Characteristics

Drawing on the Code for Fire Protection Design of Cultural Heritage Buildings, a "core-peripheral" dual protection zone is divided:

1) Core Protection Zone: Covering the building itself and the adjacent 5 m range, prohibiting hot work, using non-combustible materials for wall restoration, and setting a fire separation zone with a width of no less than 3 m;

2) Peripheral Protection Zone: Located 20 - 50 m outside the core zone, transforming existing streets into fire-fighting access with a bearing capacity of no less than 15 t (to meet the passage of light fire-fighting vehicles), and using natural conditions such as water systems and green spaces to build fire separation.

6.1.3. Special Protection Plans Based on Functional Types

Targeting the risk characteristics of different functional types of buildings, special strategies are formulated:

1) Residential Buildings: Focus on rectifying electrical hazards, replacing aging lines with flame-retardant cables, installing electrical fire monitors; standardizing evacuation channels, clearing debris to ensure a width ≥ 0.9 m;

2) Commercial Buildings: Controlling the stacking of combustible goods, setting up fire separation shelves; installing smart electricity systems with automatic power cutoff when overloaded; equipping smart fire-fighting APPs to realize information exchange between merchants and fire departments;

3) Ancestral Halls: Setting up independent sacrificial areas, separated from the main space by fire-proof glass; installing aspirating smoke detectors, with additional temperature sensors in the ceiling; equipping high-pressure water mist systems to protect timber frames;

4) Industrial Heritage: Removing residual dangerous goods and sealing abandoned pipelines; coating steel roof trusses with fire retardant coatings to increase the fire resistance limit to 1.5 h; setting up large-space intelligent fire suppression devices.

6.2. Whole-Life-Cycle Technology Application Path

6.2.1. Repair Stage: Synchronous Implementation of Fire Protection Measures

Following the principle of "structure reinforcement first, then fire protection" in the Strategy and Technical Guidance for Improving Fire Protection Performance of Guangzhou historic Buildings, three tasks are carried out simultaneously during the repair stage:

1) Hidden Danger Inspection: Using non-destructive detection technology to comprehensively inspect hidden dangers such as carbonization of timber components and line aging, forming a Fire Hazard Assessment Report;

2) Structure Reinforcement: Performing splicing or replacement of decayed timber components, using new components with fire protection treatment; grouting

and reinforcing weathered walls, while injecting fire-proof mortar;

3) Facility Installation: Concealed installation of fire protection facilities, such as embedding temperature sensors inside beam frames and laying fire-fighting pipelines in the ceiling. In the Yongqingfang repair project, fire protection measures accounted for 30% of the total construction period, ensuring synchronous completion and acceptance with the repair project.

6.2.2. Adaptive Reuse Stage: Technology Adapting to Functional Needs

During functional transformation, technical measures need to be accurately matched with new functions:

1) Cultural Tourism Functions: Adding intelligent evacuation indication systems to dynamically adjust evacuation routes according to passenger flow density; installing passenger flow monitoring systems to avoid overcrowding; setting up portable fire extinguishing equipment for easy access;

2) Commercial Functions: Using fire separation materials to divide stores, with a fire resistance limit of 2.0 h; installing oil fume purification and fire damper linkage systems to avoid kitchen fires; configuring smart fire-fighting APPs to realize information exchange between merchants and fire departments;

3) Residential Functions: Adopting wireless alarm systems to reduce line laying; installing gas leakage alarms with linked valve cutoff; equipping simple fire extinguishers and escape masks to improve self-rescue capabilities.

6.2.3. Operation Stage: Dynamic Monitoring and Maintenance

Establishing a closed-loop mechanism of "monitoring-evaluation-maintenance":

1) Daily Monitoring: Users inspect the appearance of fire protection facilities daily, professional institutions conduct functional tests monthly, and the platform conducts comprehensive evaluations quarterly;

2) Regular Maintenance: Fire protection facilities are maintained once every six months, and the flame-retardant coatings of timber components are re-inspected once every three years, with aging parts repainted;

3) Dynamic Adjustment: Optimizing fire protection measures in a timely manner based on changes in usage functions or hidden danger inspection results. For example, after increasing the frequency of sacrificial activities in an ancestral hall, the fire warning sensitivity level is increased to shorten the response time.

6.2.4. Post-Disaster Stage: Integration of Restoration and Performance Improvement

After fires or other disasters, an "restoration + improvement" model is adopted:

1) Damage Assessment: Using ultrasonic, thermal imaging, and other technologies to evaluate the damage degree of components, distinguishing between repairable and replaceable parts;

2) Restoration and Reinforcement: Repairing damaged timber components after fire protection treatment, and replacing burned parts with components of a higher fire resistance level;

3) System Upgrade: Upgrading technical measures for exposed weak links, such

as increasing the density of detectors and optimizing the coverage of fire suppression systems.

7. Management Mechanism and Guarantee System for Fire Protection of Guangzhou Historic Buildings

7.1. Multi-Subject Collaborative Responsibility System

7.1.1. Responsibility Division of Three Parties

A "government-property owner-user" three-party responsibility system is built to clarify the boundary of rights and responsibilities (Table 5).

Table 5. Fire protection responsibility system for Guangzhou historic buildings.

Responsible Subject	Core Responsibilities	Specific Tasks	Assessment Mechanism
Government Departments	Supervision and service	Formulating standards, supervision and inspection, providing technical guidance, organizing emergency drills	Annual assessment, linked to department performance
Property Owners	Main responsibility	Bearing fire protection transformation costs, entrusting professional institutions for detection, and equipping fire protection facilities	Included in credit evaluation, joint punishment for dishonesty
Users	Daily management	Daily inspection, clearing hidden dangers, operating fire protection facilities, and reporting dangers	Signing responsibility letters, penalties for violations
Responsible Subject	Core Responsibilities	Specific Tasks	Assessment Mechanism

This system clarifies the responsibilities of all parties through the Fire Protection Agreement, which is compulsorily implemented in projects such as Yongqingfang, with a responsibility implementation rate of 100%.

7.1.2. Cross-Department Collaboration Mechanism

A "joint meeting + joint law enforcement" mechanism of four departments (housing and urban-rural development, fire rescue, cultural heritage, and planning) is established:

1) Joint Meetings: Held once a quarter to coordinate the resolution of cross-departmental issues, resolving 23 approval and technical problems in 2024;

2) Joint Law Enforcement: Conducting special inspections once every six months, focusing on inspecting the implementation of fire protection measures in adaptive reuse projects, and investigating 17 illegal acts in 2025;

3) Information Sharing: Establishing a historic building protection information platform, integrating data from various departments to realize information ex-

change on hidden danger inspection, approval, and law enforcement.

7.1.3. Professional Technical Support System

A three-level technical support network is established:

1) Municipal Expert Committee: Composed of 20 experts in architectural heritage, fire protection, and structure, responsible for the evaluation and technical demonstration of major projects;

2) Professional Service Institutions: Identifying 15 enterprises with both cultural heritage protection and fire protection qualifications, providing integrated detection, design, and construction services;

3) Grassroots Technical Personnel: Equipping 2 - 3 full-time fire protection technicians for each historic district, responsible for daily technical guidance.

7.2. Whole-Life-Cycle Management Process

7.2.1. Pre-Evaluation Stage

1) Value Evaluation: The cultural heritage department organizes experts to evaluate the core value elements of the building, clarifying the forbidden zone for fire protection transformation;

2) Risk Evaluation: Using a "qualitative + quantitative" method, combining PyroSim simulation and on-site detection to determine the fire risk level;

3) Plan Design: Qualified institutions compile fire protection plans, which are reviewed and approved by the expert committee before implementation.

7.2.2. Implementation Stage

1) Construction Supervision: Implementing a "dual supervision" system, with cultural heritage supervisors responsible for style protection and fire protection supervisors responsible for technical quality;

2) Process Detection: Key processes (such as flame retardant treatment, facility installation) must pass detection before entering the next process;

3) Concealed Works Acceptance: Conducting special acceptance of concealed fire protection facilities and retaining image data for filing.

7.2.3. Operation Stage

1) Daily Management: Users conduct weekly inspections in accordance with the Daily Inspection and Maintenance Form for Fire Hazards of Guangzhou historic Buildings, recording hidden danger rectification;

2) Regular Detection: Professional institutions conduct comprehensive detection once every six months, using non-destructive technology to evaluate the fire protection performance of components and the function of facilities;

3) Emergency Management: Formulating special emergency plans, organizing emergency drills twice a year, and optimizing evacuation processes based on the spatial characteristics of historic buildings.

7.2.4. Exit Stage

Before changing the building function or demolition, fire protection facility recycling and risk evaluation are carried out:

1) Facility Recycling: Recyclable fire protection facilities (such as detectors, fire extinguishers) are recycled for reuse after passing detection;

2) Risk Evaluation: Formulating fire protection plans during demolition, equipping fire extinguishing equipment, and monitoring the entire process of hot work;

3) Archive Filing: Sorting out fire protection data throughout the life cycle and incorporating it into the historic building protection archive.

7.3. Guarantee Measures and Public Participation

7.3.1. Fund Guarantee Mechanism

A diversified fund system of "government subsidies + property owner investment + social donations" is established:

1) Government Subsidies: Providing 70% and 50% fire protection transformation subsidies for Level 1 and Level 2 protected buildings, respectively;

2) Property Owner Investment: Clarifying that property owners bear the main investment responsibility, which is included in property registration and transaction conditions;

3) Social Donations: Establishing a special fund for fire protection of historic buildings and encouraging donations from enterprises and social organizations.

7.3.2. Technical Standard Guarantee

A technology transformation system of "R&D-standard-application" is improved:

1) R&D Platform: Establishing a fire protection technology R&D center for historic buildings relying on the State Key Laboratory of Subtropical Building Science, South China University of Technology;

2) Standard Formulation: Updating the Technical Specification for Fire Protection of Historic Protected Buildings annually to incorporate the latest technological achievements;

3) Promotion and Application: Establishing a new technology pilot mechanism, promoting it comprehensively after successful trials in 3 - 5 buildings.

7.3.3. Public Participation Mechanism

A multi-level public participation system is built:

1) Publicity and Education: Setting up fire protection popular science corridors in historic districts, pushing fire protection knowledge through new media, and carrying out the "Historic Building Fire Protection Publicity Week" activity annually;

2) Volunteer Services: Establishing a "historic Building Fire Protection Volunteer Team" to carry out daily inspections and publicity guidance, with more than 2000 volunteers currently;

3) Opinion Collection: Publicly collecting opinions from the public in the preparation of fire protection plans and emergency plans to improve the feasibility and acceptance of measures.

8. Conclusions and Prospects

8.1. Main Conclusions

Historic buildings in Guangzhou are characterized by "diversified types, dense layout, and flammable materials", with a composite fire risk mechanism of "innate defects + acquired superposition + environment-induced factors". Among them, ancestral halls exhibit the fastest fire spread rate, while residential buildings account for the highest proportion of fires.

Guangzhou has established a nationally leading "regulation-guideline-specification" three-tier fire protection policy system, with core innovations including value-prioritized evaluation, performance-based exemption, and multi-department collaboration, which adapts to both national standards and local realities. Meanwhile, the traditional fire protection wisdom of Guangfu architecture has been transformed and applied, and heritage-friendly technologies have realized the balance between heritage preservation and safety assurance. Guangzhou has constructed a strategy integrating "hierarchical and zoned protection + whole-life-cycle application + multi-subject collaboration", which has reduced the fire incidence rate of key historic buildings, achieving a win-win situation between fire safety and heritage protection.

8.2. Experience and Insights

The core experience of fire protection for Guangzhou historic buildings can be summarized as "four integrations":

1) Integration of Tradition and Modernity: Instead of separating historical context, the modern value of traditional wisdom is explored and activated through technological innovation, avoiding "one-size-fits-all" modern transformation;

2) Integration of Policies and Technologies: The policy framework defines the boundary for technology application, and technological innovation provides support for policy implementation, forming a positive cycle of "standards guiding technology and technology improving standards";

3) Integration of Safety and Style: Using concealed and miniaturized technical measures to integrate fire protection facilities into the architectural style, realizing "invisible protection";

4) Integration of Government and Society: Building a multi-subject responsibility system through funding guarantees and public participation, forming a pattern of the whole society jointly protecting historic buildings.

8.3. Research Prospects

With the continuous improvement of the smart fire protection technologies, the fire protection work for historic buildings in Guangzhou will fully shift from "passive response" to "active prevention", providing solid safety guarantees for the revitalization of old cities and offering a replicable "Guangzhou experiences" for fire protection of similar historic buildings in China and even globally.

8.4. Limitation

The "Guangzhou experiences" for historic building fire protection have clear applicability conditions, being particularly suitable for high-density historic districts in humid-heat regions—a context that aligns with Guangzhou's climatic characteristics and urban spatial layout, but may have limitations in regions with sparse historic building distribution or arid/cold climates. For other cities to replicate this model, targeted adjustments to the policy cycle and implementation paths are required. Additionally, for regions with insufficient public funding, exploring Public-Private Partnership (PPP) models can complement funding gaps and ensure the sustainability of fire protection work.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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