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Construction and Application of a Protection Monitoring and Evaluation Management System for Guangzhou, a Historical and Cultural City, from a Life Cycle Perspective

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Abstract Amid the comprehensive progression of urban renewal initiatives, the protection of historical and cultural cities is evolving from "static control" to "dynamic governance". As one of the earliest designated national historical and cultural cities, Guangzhou possesses heritage resources characterized by an extensive temporal range, broad spatial distribution, and diverse types of elements. In response to the current industry shortcomings of existing digital platforms for the protection of famous cities in China, such as an overemphasis on construction rather than operation and maintenance, outdated static control methods, a lack of quantitative assessment, and limited application of artificial intelligence, this article adopts life cycle theory (LCT) as its central guidance, and integrates BIM, digital twin, unmanned aerial vehicle (UAV) inspection, and artificial intelligence (AI) technology to independently develop the CAN • HERITAGE platform. The article analyzes the comprehensive operational logic of heritage resource protection, establishes four collaborative functional sections: digital twin, real-time monitoring, sky eye inspection, and AI brain, and further develops an innovative eight-dimensional monitoring and evaluation index system. Through four implementation scenarios, multi-scale spatio-temporal reconstruction, quantitative physical examination and assessment, three-dimensional planning and control, and AI-based intelligent judgment, the CAN • HERITAGE platform accomplishes a panoramic digital reproduction spanning from the macro urban context to individual buildings at the micro level. This article broadens the application of LCT within the domain of historical and cultural protection in densely populated megacities, and proposes a comprehensive management pathway for the protection, monitoring, and evaluation of historical and cultural cites from file management and dynamic monitoring to risk control and iterative optimization, offering a replicable and scalable model, exemplified by the "Guangzhou case", to guide the intelligent transformation of comparable cities nationwide.

Keywords Digital twin, Artificial intelligence, Historical and cultural protection, Real-time monitoring, Guangzhou

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Guangzhou has a history spanning more than 2,200 years, dating back to the establishment of Nanhai Prefecture during the Qin Dynasty. It is among the first group of national historical and cultural cities designated by the State Council of China[1], characterized by a city site that has remained unchanged for a millennium, a continuous urban layout, and the integration of diverse cultures. In October 2018, during his inspection of Guangzhou, General Secretary Xi Jinping explicitly emphasized the need to "infuse new vitality into the old city". He highlighted that urban planning and construction in Guangzhou should prioritize the protection of historical and cultural heritage, avoid pursuing rapid success and short-term gains, and refrain from large-scale demolition and reconstruction. At the national policy level, competent authorities, including the Ministry of Housing and Urban-Rural Development and the Ministry of Natural Resources, have underscored the importance of advancing the surveying, mapping, archiving, database development, and information platform construction for historical buildings in famous cities. These efforts are important measures to implement national policies and requirements for the protection of such cities. Currently, the comprehensive advancement of the urban renewal initiative, coupled with Guangzhou's high-density development pattern and the numerous dispersed historical and cultural protection objects, presents significant challenges to the intelligent and precise governance of famous city protection.

Numerous historical and cultural cities in China have engaged in exploratory efforts and practical applications in the development of digital information platforms, resulting in a phased and differentiated development pattern. These initiatives have contributed valuable experience toward the intelligent protection of Guangzhou City. However, they have also revealed common deficiencies within the industry. During the initial stages of development, cities such as Nanjing and Xi'an predominantly utilized traditional technologies, including ArcGIS, to establish foundational platforms. These efforts emphasized the integration of heritage data and ledger management, the construction of a regional spatial resource system for historical and cultural cities, and the preliminary realization of functions such as digital analysis, resource integration, and shared services for historical and cultural resources[2]. At this stage, the primary focus was on the collection and static presentation of fundamental data. Technically, the process remained heavily dependent on two-dimensional ledgers and manual inspection management. A prevalent issue was the prioritization of construction over management, leading to inadequate availability of real-time data and low efficiency in cross-departmental collaboration. However, with the

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integration of advanced technologies such as CIM and digital twin, the digital development of famous cities is progressively advancing toward intelligent decision-making and dynamic governance and control.

For example, the Suzhou CIM platform has developed a five-step process for the protection and renewal of the ancient city, consisting of identification, organization, planning, review, and evaluation, to create a comprehensive digital representation of the ancient city of Suzhou[3]. The Beijing Historical and Cultural City Smart Platform, guided by the *Regulations on the Protection of Beijing Historical and Cultural City* and addressing the full-cycle management requirements of 11 categories of legally protected objects in Beijing, has established a comprehensive digital governance system encompassing identification and registration, protection and management, utilization and inheritance, as well as implementation and supervision, facilitating the transition from static data management to dynamic smart governance in the protection of famous cities[4]. At this stage, the effectiveness of protection platforms for famous cities is primarily assessed through qualitative methods, lacking a scientific and quantitative evaluation system. Furthermore, the integration of artificial intelligence technologies remains inadequate, hindering the ability to address the comprehensive protection requirements encompassing all elements, cycles, and dimensions of these cities. Consequently, the development of a technologically advanced, meticulously managed, and intelligent protection system for famous cities has emerged as a critical and central issue within the field.

Guangzhou places significant emphasis on the protection and inheritance of the historical and cultural city. In the development of information platforms, the city has established a comprehensive thematic "one-map" database encompassing historical and cultural resources across the entire region. This database includes a total area of 25.43 km^2 designated as historical and cultural protection lines and is integrated with the municipal territorial spatial information platform[1]. Utilizing high-precision laser point cloud data and high-standard building BIM models, Guangzhou has completed three-dimensional mapping and documentation of 828 historical buildings, 26 blocks (336 hm^2), and 140.6 km of traditional street facades, forming the digital foundation of "Guangzhou CIM+ Famous City"[5]. However, when examining the prevalent challenges in the development of the domestic industry and Guangzhou's specific protection practices, a significant issue emerges regarding the inadequate practical application of artificial intelligence, dynamic monitoring, and related technologies within the current system. How to leverage the existing digital construction infrastructure, integrate next-generation digital intelligence technologies in alignment with actual business needs, and implement precise, "embroidered" protection requirements has become an urgent practical issue in the current protection efforts of Guangzhou, a city rich in history and culture.

In response to these challenges, this article presents the development of the CAN • HERITAGE platform, designed to address key industry issues and technical limitations in the protection of historical and cultural heritage, such as the prevalent focus on construction rather than management, and on reporting rather than operation and maintenance. Aiming for comprehensive coverage of multi-level elements and refined lifecycle management, the platform integrates diverse heterogeneous data from historical buildings, cultural districts, intangible cultural heritage resources, and other protected objects to establish a two-dimensional and three-dimensional integrated heritage resource data foundation. It further incorporates real-time dynamic monitoring, AI-based risk early warning, and intelligent decision-support functions, thereby facilitating a shift in heritage protection from passive remediation to proactive prediction and precise control. This approach has yielded a distinctive pathway for the intelligent protection of famous cities, tailored to the high-density urban context of Guangzhou, and offers novel technical solutions and practical insights for the refined and intelligent protection of historical and cultural heritage in major domestic megacities.

1 Theoretical basis and cons–truction ideas

1.1 Core connotation of life cycle theory (LCT)

LCT, originally developed within the biological sciences, describes a sequence of changes in the form or function of living organisms throughout their evolutionary lifespan. Its fundamental logic encompasses the entire life process experienced by an organism, from birth and growth to aging and death[6]. Although LCT primarily pertains to living entities, analogous processes of change are observed in many non-living systems. Consequently, LCT has been extensively adapted and applied, serving as a foundational theoretical support in areas such as territorial spatial planning[7], natural resource management, and the protection of historical and cultural heritage[8-9]. Historical and cultural heritage should not be regarded as a static or fixed resource; rather, its comprehensive developmental trajectory, including file management, dynamic monitoring, risk control, and iterative optimization, exhibits distinct dynamic evolutionary characteristics consistent with the core principles of LCT.

This article, considering the protection and governance requirements of Guangzhou as a historical and cultural city, reconstructs a life cycle connotation appropriate for the protection of such cities. Centered on historical and cultural heritage resources, it establishes four closed-loop governance stages: file management, dynamic monitoring, risk control, and iterative optimization. These stages serve as the top-level guiding logic for the design and scenario implementation of the CAN • HERITAGE platform.

1.2 Construction ideas and goals

Drawing upon the dynamic governance logic of the life cycle and addressing the limitations of digital construction in the protection of domestic famous cities, as well as the challenges associated with density management in the development of Guangzhou as a megacity, this study proposes a core construction idea centered on theoretical guidance, data-driven foundations, technological empowerment, scenario-based implementation, and multi-stakeholder co-governance. This framework serves as the guiding principle for the development of the CAN • HERITAGE platform. Firstly, it advocates for the establishment of a comprehensive data resource system to systematically identify the "assets" involved in the protection of famous cities, enabling the spatio-temporal and digital transformation of historical and cultural resources, and addressing industry challenges related to fragmented data and inefficient management. Secondly, the study emphasizes the development of functional modules compatible with full-process control, establishes a quantitative assessment system, and investigates a novel model transitioning from "passive protection" to "proactive early warning". The ultimate objective is to enrich and enhance the application system of LCT in the protection of historical and cultural cities, thereby providing both a theoretical framework and practical case studies to inform similar cities.

2 Technical framework and module design

2.1 Overall technical framework

In response to the life cycle governance requirements for the protection of Guangzhou

as a historical and cultural city, the CAN • HERITAGE platform employs a hierarchical modular architecture. It establishes a comprehensive four-tier technical system comprising the support layer, data layer, model layer, and functional layer (Fig.1), thereby creating a closed-loop operational mechanism encompassing file management, dynamic monitoring, risk control, and iterative optimization. Specifically, the support layer offers fundamental technical support through the utilization of front-end frameworks, three-dimensional engines, databases, and related technologies. The data layer integrates multisource data, including topography and landforms, remote sensing images, architectural models, and attribute ledgers, to construct a standardized digital foundation for heritage protection. The model layer develops monitoring and evaluation models and AI-based intelligent analysis models for famous cities to facilitate quantitative data analysis and informed decision-making. Finally, the functional layer delivers four core functional modules that comprehensively address the requirements of life cycle governance scenarios.

2.2 Design of the four core functional sections

Based on a four-tier technical architecture and the governance logic of the heritage life cycle, the CAN • HERITAGE platform has developed four primary functional sections: digital twin, real-time monitoring, sky eye inspection, and AI brain. These sections correspond respectively to the four fundamental stages of the heritage life cycle: file management, dynamic monitoring, risk control, and iterative optimization, thereby facilitating a comprehensive integration of technical architecture with functional application.

2.2.1 Digital twin section: digital archive management stage of the life cycle. The digital twin section corresponds to the "archiving and management" stage within the life cycle of famous city protection, fulfilling functions related to digital resource archiving, spatial analysis, and visual representation. This section is founded upon a unified three-dimensional digital base map encompassing the entire city, integrating authentic three-dimensional models of historic urban areas, key heritage buildings, BIM individual models of streets and alleys, as well as laser-scanned point cloud models. It also superimposed specialized layers, including the red line designating historical protection planning and construction control zones. A standardized digital resource library is established based on a six-tier classification system encompassing municipal spatial structure, historic urban areas, historic and cultural blocks, cultural relic protection units, historic buildings, and intangible cultural heritage, thereby facilitating the integration and interoperability of multi-source heterogeneous data. Furthermore, specialized analytical tools, such as height control analysis, sightline corridor analysis, and skyline analysis, have been developed to provide precise spatial foundations for diverse planning analyses and protection decision-making processes. This approach enables a comprehensive digital representation of protected objects, spanning from macro-level urban patterns to micro-level individual units.

2.2.2 Real-time monitoring section: dynamic monitoring stage of the life cycle. The real-time monitoring section addresses the ongoing surveillance and protection requirements of historical and cultural heritage, aligning with the dynamic monitoring stage within the life cycle of famous city protection. This section integrates multi-source big data, including mobile phone signaling and internet public opinion, to construct a monitoring and evaluation index system encompassing eight core dimensions such as heritage protection, cultural inheritance, quality of life, and population vitality. This system facilitates quantitative assessments and multidimensional evaluations of the condition of protected objects, the effectiveness of pro-tection efforts, and the vitality of regional development. It further generates comprehensive monitoring reports, enables comparative analyses of protection outcomes across different urban areas, and dynamically tracks the impact of key renovation projects, providing essential data support and a quantitative foundation for the dynamic monitoring of famous city protection.

2.2.3 Sky eye inspection section: risk management stage of the life cycle. The sky eye inspection section addresses the risk management requirements associated with cultural heritage. To overcome challenges such as narrow streets and alleys, numerous concealed structures, and blind spots inherent in manual inspections within historic urban areas, it has developed an integrated air-ground intelligent supervision system utilizing unmanned aerial vehicles (UAV) technology. This system implements "designated flight inspection routes in famous cities" to conduct periodic surveys of key historical and cultural protection zones and is equipped with real-time image transmission capabilities to promptly identify illegal constructions, unauthorized modifications to historical buildings, and other violations. Meanwhile, the system automatically archives inspection videos, creating a comprehensive historical image archive of UAVs which serves as evidentiary support for law enforcement and facilitates research on historical changes. This approach effectively mitigates the limitations of traditional manual inspections, enabling regular risk prevention and control, ensuring full-process traceability, and reinforcing the safety bottom line throughout the heritage life cycle.

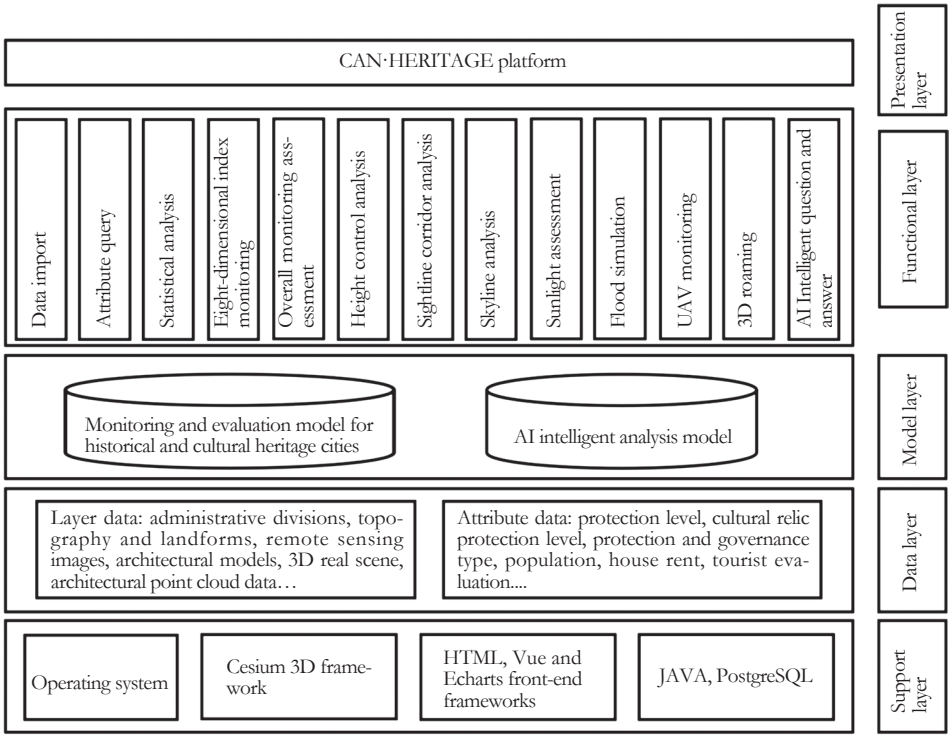

Fig.1 Architecture of the CAN · HERITAGE platform

2.2.4 AI brain section: iterative optimization stage of the life cycle. The AI brain section functions as the central hub for the iterative optimization of the life cycle management of famous city protection. Utilizing extensive business data, policy standards, and accumulated case studies, the system constructs a specialized AI large model and knowledge base tailored to the domain of famous city protection. This platform offers capabilities such as intelligent policy question and answer, automated review of planning schemes, generation of protection strategies, and analysis of heritage evolution trends. Consequently, it significantly enhances the efficiency and expertise involved in the protection of famous cities, facilitating a shift from reactive approaches to proactive prediction and continuous iterative improvement.

3 Typical application scenarios

3.1 Panoramic famous city and spatio–temporal reconstruction

3.1.1 Time dimension: digital narrative of historical evolution. The CAN • HERITAGE platform has developed a time axis of Guangzhou urban development spanning from the Qin Dynasty to the present day. This time axis visually depicts the evolution of the city's administrative boundaries and urban layout over more than 2,200 years. The platform also integrates a variety of historical materials, including maps, documents, and photographs, to create an immersive environment that facilitates the digital narrative and inheritance of the city's historical and cultural context.

3.1.2 Spatial dimension: hierarchical control from macro to micro levels. In terms of spatial dimensions, the CAN • HERITAGE platform has developed a three-tiered interactive hierarchical control system of macro, meso, and micro levels to address the archiving and management requirements of heritage across varying scales. At the macro (national and provincial) level, planar spatial data from 143 national historical and cultural cities nationwide, as well as 8 national and 15 provincial historical and cultural cities within Guangdong Province, have been integrated. This integration emphasizes Guangzhou's central role within the cultural landscape of South China and the broader nation. At the meso (urban layout) level, the platform reconstructs and presents the natural and cultural integration patterns of "mountains, water, cities, villages, fields, and the sea" in Guangzhou.

Firstly, the Pearl River Cultural Belt and the Liuxi River Cultural Belt should be designated as the primary axes for safeguarding the city's historical and cultural heritage, thereby linking various cultural resources along these corridors. Secondly, specific zones are delineated, encompassing the central urban area and ten "charming scenic areas", including Shawan, Lianhua Mountain, and the ancient post road along the Liuxi River, to promote regional integration and the distinctive protection of cultural resources. Thirdly, spatial control is implemented over significant mountain and water systems, such as Baiyun Mountain, thereby reinforcing the ecological and spatial foundation necessary for the protection of the city's historical and cultural resources. At the micro (urban and individual) scale, emphasis is placed on four categories of core protection carriers: 26 historical and cultural blocks, 22 historical style areas, 13 traditional Chinese villages, and 73 municipal traditional villages. Through precise spatial positioning of each protected object, the establishment of comprehensive attribute files, including essential information such as building age, architectural style, protection status, and renovation history, and the continuous updating of dynamic data, this approach provides fundamental data support for targeted "micro-renovations" and renovations characterized by an "embroidered" style.

3.2 Multi–source data–driven physical examination and assessment

By integrating multi-source open-source big data, including mobile phone signaling, internet public opinion, and commercial data, and drawing upon the multi-factor evaluation model proposed by Guan Wenjun et al.[10], this study constructs an eight-dimensional evaluation index system for monitoring famous cities. This system aligns with the core requirements for the protection and development of historical urban areas in Guangzhou and encompasses eight dimensions: heritage protection, cultural inheritance, quality of life, population vitality, economic resilience, social image, technological innovation, and policy management. It facilitates regular quantitative health assessments and horizontal comparisons of overall appearance protection, human settlement vitality, governance effectiveness, and economic development within historical urban areas, thereby enabling a comprehensive evaluation of their vitality and resilience (Table 1).

In practical applications, the CAN • HERITAGE platform facilitates horizontal comparisons and annual dynamic monitoring of the protection effectiveness across various administrative districts, streets, and historical and cultural blocks, and enables the comparative assessment of governance strengths and weaknesses within each dimension. For example, in key urban renewal areas such as Yongqingfang and Duobao Sub-district, the social benefits and revitalization outcomes of renewal projects are dynamically evaluated using specific indices, including "the attractiveness to middle-aged and young permanent residents", "the vitality of tourism industry", and "the construction volume of public open spaces (e.g., parks, green spaces, squares)". This evaluation determines whether the renewal projects effectively attract younger populations, enhance economic benefits, and improve the quality of life for original residents, thereby providing a quantitative foundation for the subsequent optimization of protection strategies and iterative project upgrades.

3.3 Planning control and repair assis–tance

The CAN • HERITAGE platform, utilizing high-precision three-dimensional models, independently develops and integrates multiple specialized three-dimensional spatial analysis tools. It offers scientific and quantitative technical support for the protection and management of historical and cultural heritage, thereby effectively addressing the limitations of traditional management models for the protection of famous cities, which are primarily qualitative and lack sufficient quantitative analysis.

3.3.1 Refined planning and control of historical urban areas. The historical urban area is the core spatial unit and stylistic carrier essential for the protection of famous cities. The CAN • HERITAGE platform utilizes real-scene three-dimensional modeling technology to develop a high-precision, total element three-dimensional model system for historical urban areas. This system accurately reconstructs the spatial configuration and textures of key protected elements, including city walls and gates, historical water systems, and traditional streets and alleys, thereby providing a visual and quantifiable spatial foundation to support refined management and control.

(1) Full-cycle protection and spatial early warning of city wall ruins. The spatial forms of ancient city ruins spanning from the Qin Dynasty to the Qing Dynasty have been accurately replicated, facilitating digital protection and dynamic visualization of their layouts. Concurrently, a spatial early warning and control system has been integrated to safeguard key subterranean cultural relic burial sites, such as the Site of the Nanyue Kingdom Palace. By superimposing and analyzing the spatial boundaries of new and expanded construction projects, potential risks of structural damage are mitigated through technical means, thereby enabling coordinated protection and full-cycle

risk prevention and control throughout the entire lifecycle of both aboveground and underground cultural resources.

(2) Multi-dimensional and three-dimensional analysis tools empower planning approval. The CAN • HERITAGE platform, built upon a three-dimensional digital foundation, incorporates a suite of specialized analytical tools tailored for the management and control of the historical urban area's visual characteristics. Notably, the Height Control Analysis tool assesses whether newly constructed or renovated buildings comply with the height restrictions established for historical urban zones. The Sight Corridor Analysis tool simulates the transparency effects of the core mountain and water sight corridor extending from Zhenhai Tower on Yuexiu Mountain to the Pearl River, thereby preserving the integrity of the ancient city's mountain and water spatial configuration. The Skyline Analysis tool facilitates the dynamic optimization of architectural forms and community outlines to maintain the harmonious silhouette of the historic cityscape. Furthermore, the platform integrates environmental resilience assessment tools, including sunlight evaluation and flood simulation (inundation analysis), addressing both stylistic protection and safety resilience requirements. Collectively, these tools provide a multidimensional, quantitative foundation for the evaluation of planning schemes and the control of construction projects within historical urban areas, thereby advancing the transition from traditional empirical control methods to data-driven, refined governance.

3.3.2 Regular risk control in historical urban areas. In addressing the governance challenges inherent in historical urban areas characterized by dense street layouts, numerous concealed spaces, and limited scope of manual inspections, the CAN • HERITAGE platform has developed a three-dimensional inspection system utilizing UAVs within its sky eye inspection section. This system employs standardized inspection routes to perform periodic aerial photography, enabling the rapid identification of unauthorized modifications and illegal constructions through real-time image transmission. Meanwhile, archived temporal images are maintained as evidentiary materials to facilitate ongoing risk management of historical features across the region. The principal functions of this system are as follows.

(1) Regular periodic inspection mechanism. The system utilizes data on historical and cultural protection boundaries to delineate standardized and fixed exclusive flight inspection routes for famous cities, encompassing core control areas such as historical and cultural zones and construction control zones. This approach establishes a systematic and periodic aerial photography inspection mechanism, enabling comprehensive and regular surveillance of key protected areas.

(2) Real-time image transmission and rapid verification. The CAN • HERITAGE platform features a real-time image transmission capability that allows for the immediate transmission of aerial images. This functionality enables managers to remotely monitor on-site conditions in real time, promptly identify illegal constructions, unauthorized modifications to buildings, and damage to their appearance, and establish an efficient response system for the rapid detection, analysis, and resolution of issues.

(3) Collection and management of time-series image archives. The CAN • HERITAGE platform automatically classifies and archives images and video data obtained from previous UAVs inspections, thereby creating a dynamically updated image archive that captures the spatio-temporal evolution of heritage sites. This functionality facilitates temporal traceability and process retention of historical appearance changes, offering data support for analyzing appearance variations, verifying construction activities, and collecting evidence for compliance purposes.

3.4 AI intelligent question and answer system of famous cities

In response to business requirements such as large-scale data retrieval, planning text processing, intelligent scheme analysis, and official document generation within the planning and management contexts of Guangzhou as a historical and cultural city, the CAN • HERITAGE platform has developed a dedicated large-scale AI model, referred to as the AI brain, specifically tailored for the domain of famous cities. This AI brain employs a hierarchical, scenario-based intelligent service architecture, decomposing its capabilities into two primary modules: fundamental general planning scenarios and specialized professional business scenarios related to the governance of famous cities (Fig.2). This design aims to establish an industry-specific intelligent assistant optimized for the refined governance and protection of Guangzhou's cultural heritage.

3.4.1 Fundamental scenario: general intelligent support capabilities for famous city protection planning. The fundamental scenarios emphasize the routine, high-frequency, and essential tasks performed by professionals involved in the protection and planning of famous cities. These scenarios encompass four core capabilities: planning retrieval, planning summarization, planning comparison, and planning generation. By leveraging the text comprehension, information extraction, text summarization, multi-scheme comparison, and content generation functionalities of large-scale models, this approach

Table 1 Index system of the eight–dimensional evaluation model

Evaluation dimension	Primary index	Secondary index
Heritage protection	Individual building	Protection level of cultural heritage
	Environmental element	Protection level of natural environment and landscape pattern
	Construction behavior	Standardization level of construction behavior
Cultural inheritance	Heritage revitalization	Revitalization level of cultural heritage
	Cultural activity	Vitality of traditional culture
Quality of life	Public space	Construction volume of public open spaces (parks, green spaces, squares, etc.)
	Transportation facility	Road smoothness
		Distribution balance of public transportation stops
	Living facility	Coverage of fire protection facilities
		Coverage of garbage collection sites
		Coverage of farmers' markets
		Coverage of sanitation facilities
Population vitality	Permanent resident population	Vacancy of houses in historical and cultural districts
		Attractiveness to middle-aged and young permanent residents
Economic resilience	Value	Housing rental level
	Industrial vitality	Vitality of tourism industry
Social image	Influence	Public attention
		Satisfaction with media evaluation
	Satisfaction	Public satisfaction
Technological innovation	Intelligent management	Construction level of management platforms
	Technology application	Application level of technological innovation in the protection of cultural heritage
Policy management	Management	Policy support intensity
		Implementation of protection plans
	Fund	Government capital investment



Fig.2 Schematic diagram of AI brain functional interface

addresses challenges commonly encountered in traditional planning workflows, such as prolonged data retrieval times, fragmented document organization, inefficient scheme referencing, and extended initial draft preparation cycles.

3.4.2 Professional scenario: in-depth decision-making empowerment capabilities throughout the entire process of famous city governance. The professional scenarios are meticulously designed to align with the fundamental administrative functions involved in the protection of Guangzhou's historical and cultural heritage. These functions encompass administrative performance, project supervision, decision support, and result archiving. The model's specialized fine-tuning capabilities are customized for four critical scenarios: consultation response, academic manuscript composition, project plan evaluation, and specialized work reporting. This approach effectively integrates the entire operational cycle, spanning from public opinion collection and think tank deliberation to project review and annual work assessment.

4 Conclusions

Guided by LCT and incorporating advanced digital technologies, including BIM, digital twin, artificial intelligence, and UAV inspection, this study presents the comprehensive architectural design, functional development, and scenario implementation of the CAN • HERITAGE platform. The platform establishes a monitoring and assessment management system for the protection of historical and cultural cities, specifically tailored to high-density urban environments in megacities. A digital protection pathway characterized by the unique features of Guangzhou, comprising file management, dynamic monitoring, risk control, and iterative optimization, has been developed. This pathway effectively broadens the application of LCT in the intelligent protection of historical and cultural heritage within densely built urban areas. Moreover, it addresses existing limitations in traditional heritage protection practices, such as reliance on qualitative control, inadequate dynamic governance, and the absence of quantitative assessment, thereby offering a practical model applicable to comparable cities across China.

Currently, the CAN • HERITAGE platform has been formally integrated into the routine operation and maintenance framework for the protection of famous local cities. This integration has significantly enhanced the efficiency and governance sophistication of heritage protection efforts in Guangzhou, serving as a critical tool for the quantitative evaluation of protection outcomes and the popularization of cultural heritage. Nonetheless, the platform presently faces several limitations in both research and practical application, including inadequate access to real-time sensor data, restricted use cases for generative AI, and the lack of a public participation mechanism. Moving forward, the CAN • HERITAGE platform will undergo continuous iteration and optimization focused on four primary objectives: technological upgrade, scope expansion, governance deepening, and value radiation. Specifically, it will: (1) deepen the integrated application of diverse digital and intelligent technologies; (2) broaden monitoring coverage by incorporating modules for emerging cultural facilities such as cultural venues and theaters, thereby establishing a comprehensive protection and monitoring system that harmoniously integrates traditional cultural heritage with contemporary culture; (3) investigate the deployment of generative AI in contexts such as the development of micro-renovation plans for historic districts and the refinement of restoration techniques for heritage buildings; and (4) enhance the platform's interactive functionalities by instituting a closed-loop public participation mechanism encompassing the entire process from clue reporting and opinion collection to adoption and feedback.

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